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THE 21ST CENTURY COWBOY: ROBOTS ON THE RANGE

*Henry H. Perritt, Jr.**

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* Retired professor of law and former dean, Chicago-Kent College of Law. Member of the bars of Virginia, Pennsylvania, District of Columbia, Maryland, Illinois, and the Supreme Court of the United States. Author of more than 100 articles and twenty-five books on dispute resolution, technology and law, and labor law. The author participated in what is now described as the "first round" of AI. See Henry H. Perritt, Jr., Artificial Intelligence Techniques for Evaluating Employee Terminations on a Personal Computer, 13 RUTGERS COMPUTER & TECH. L.J. 342 (1987) (describing expert system written by the author; explaining where the system fits in the larger context of AI). The author appreciates advice and information from Igino Cafiero of Bear Flag Robotics, who was helpful in sharing his experiences as an engineer and entrepreneur founder of a startup designing and selling robots for automating farm operations. As an engineering student at MIT, the author worked on inertial guidance systems for intercontinental ballistic missiles. More recently, he has written extensively about small drone technology, including on sensors and navigation systems for drones and on strategies for regulating them. He is a commercial helicopter pilot, a private instrument airplane pilot, and an Extra Class radio amateur (K9KDF).

I. INTRODUCTION

A. Dakota, Montana, and Texas at Work

Dakota has been on duty at the cattle ranch for thirty hours straight, without anything to eat or drink since his shift started. He is constantly in motion. He can detect immediately when an animal begins to drift away from the herd, and he moves quickly into just the correct position beside or behind it and makes an appropriate amount of noise, waving his arms if necessary, to reunite the potential stray with the herd.

Periodically, he switches places with another cowboy and roams farther away from the main herd, searching for and spotting strays and moving them back to the herd. Constantly, he is on the alert for subtle signs that an animal is sick or injured. When he spots one, he marks its location and radios the ranch house immediately so that remedial steps can be taken.

His night vision is almost as acute as his day vision. Despite his long hours on duty, his energy and enthusiasm for his job have not flagged.

Dakota seems like he would be a good audience for a union organizer trying to persuade him that he is not being rewarded sufficiently for his unusual skills, and that he is being worked too hard, in violation of federal and state wage and hour law. But Dakota is not very likely to vote for a union to represent him and the other cowboys. He is a robot.

Dakota has two robotic cousins: Montana and Texas. Montana is, like Dakota, a robocowboy, but he works in a cattle feedlot. Texas is a robotic truck-tractor that pulls a cattle hauler semi-trailer full of cattle from cow-calf operations to auction points, then to feedlots, then to another auction point, and then to a slaughterhouse. At other times, he drives frozen boxed beef to retail outlets.

Together they may represent the third wave of creative destruction in the beef industry.[1]

B. Bleak Prospects

Despite being a hard, competent worker, Dakota is unlikely to replace his human counterpart. Dakota, Montana, and Texas are skilled in the ways of the cattle industry. They do their jobs almost as well as their human counterparts.[2] The main challenge they face is getting hired. They have to earn enough to pay back the costs of their extensive preparation.

Dakota, Texas, and Montana all are technologically possible: robots can be programmed to perform essential cowboy functions on the highways, in feedlots, and on the range. Most of what they need to do can be "taught" by writing traditional computer code expressing navigation, guidance, and control algorithms.[3] They may be able to perform some of these functions better and with greater subtlety if machine learning is adapted to work with full motion video samples of human cowboys at work.

Technological possibility, however, does not mean economic feasibility or commercial success. It is far from clear that the cattle industry will be in a rush to hire robocowboys. Aside from self-driving cattle trucks, robocowboys may simply be too expensive to replace many human cowboys.

If they are not around, they do not need to be regulated. Pundits are too eager to regulate robots. Any rush to regulate robocowboys is quite premature. Careful analysis shows that many robot applications, like those in cattle ranching, potentially capable of costing jobs, are unlikely to occur because

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1. The first wave of creative destruction, considered in Henry H. Perritt, Jr., *Rise and Fall of the Cowboy: Technology, Law, and Creative Destruction in the Industrialization of the Food Industry*, 94 N.D. L. REV. 361 (2019) [hereinafter Perritt, *Rise and Fall*], replaced local cattle farms, abbatoirs, and butcher shops with range fed cattle, cattle drives to railheads, beef slaughtering in Chicago, and rail transports to retail outlets. The second wave of creative destruction, considered in Henry H. Perritt, Jr., *The Twentieth Century Cowboy: Law's Light Touch*, 9 AM. UNIV. BUS. L. REV. 143 (2020) [hereinafter Perritt, *Twentieth Century Cowboy*], replaced open-range ranching, cattle drives, rail transport to centralized beef processing facilities with smaller cow-calf farms, cattle feedlots, local beef processing plants, and truck transportation of frozen beef to retailer and directly to consumers.

2. *Twentieth Century Cowboy* begins with a story about Kirby, a twentieth century human cowboy, and Bennington, a twentieth century owner-operator cattle truck driver. *See* Perritt, *Twentieth Century Cowboy*, *supra* note 1, at 144–46.

3. Section III.A.4.c.ii explains how the basic functions of a range cowboy can be implanted in a robot; the Appendix gives an example of computer code doing this.

of economics and the difficulty of building a machine that fully replicates the fine adjustments a human worker constantly makes. Any regulation should be justified by its capacity to reduce specific risks and its cost effectiveness in doing do.

Until robocowboy designs crystallize, no one can know what risks they may present, and one cannot know the seriousness of these risks until they are actually deployed. Regulations designed around employment-applicant-selection systems or factory robots are completely unsuitable for robocowboys.[4] People who are all stirred up about the threat they think they see in a robot revolution need to calm down, learn more about what is actually happening, and wait to see what problems actually occur as various kinds of robot are introduced.

The jobs of these three types of cowboy represent a useful platform for considering the likelihood that robots will displace substantial numbers of workers. MIT economist David H. Autor is responsible for the insight that robots do not replace jobs; they replace tasks.[5] So vulnerability to automation should be assessed, the ALM Model[6] says, not by considering entire jobs, but by considering the specific tasks that comprise them. A 2018 McKinsey study accepts that invitation and projects workforce changes in terms of task vulnerability to automation.[7] The ALM model and other received wisdom teaches that the jobs most vulnerable to being displaced by automation are jobs in which most of the tasks are routine—rule-based. Those least likely to be displaced are those involving manual manipulation.[8] This analytical approach suggests that cowboys are relatively immune from being displaced by automation, despite typically having little formal education: human cowboys excel in dealing with non-routine problems, and their most important skills involve perception and mobility, not rule mastery.

Claims by commentators and journalists that robotics, backed by artificial intelligence (AI), will sweep the economy and create mass unemploy-

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4. Certain requirements for factory robots may be suitable for Montana, however, who operates in a confined environment, somewhat like a factory floor.

5. David H. Autor, *Why Are There Still So Many Jobs? The History and Future of Workplace Automation*, 29 J. ECON. PERSP. 3, 5 (2015) (arguing that likelihood of substitution of machines for humans is greatest for routine, codifiable tasks).

6. The "ALM model" refers to a model developed by MIT economists David Autor, Frank Levy, and Richard Murnane. DANIEL SUSSKIND, A WORLD WITHOUT WORK: TECHNOLOGY, AUTOMATION AND HOW WE SHOULD RESPOND 37 (2020) (describing ALM model).

7. *See* Jacques Bughin et al., *Skill Shift: Automation and the Future of the Workforce*, MCKINSEY & COMPANY (May 23, 2018), https://www.mckinsey.com/featured-insights/future-of-work/skill-shift-automation-and-the-future-of-the-workforce.

8. *See* SUSSKIND, *supra* note 6, at 38 (distinguishing tasks whose rules can be articulated from those where criteria are tacit or instinctive).

ment are considerably overblown.[9] This is certainly true in the beef industry. Robocowboys will have a place on the range and in feedlots, but the future of the range is not a robotic one.

This article, after briefly exploring the development of the cattle industry from the long cattle drives of Dodge City in the nineteenth century to the decentralized feedlots and cattle-truck networks of the twentieth in Part II, builds a foundation for considering the role of robotics in the industry in the twenty-first century, in Part III. This foundation begins with a work breakdown of what cowboys actually do. It then explains how robots work, providing a glimpse at their key technologies. Then the article explores the possibility that robots can be made to do cowboy work, providing examples of computer code that would be necessary parts of their intelligence. It concludes with an assessment of how major cultural and political movements focused on the beef industry will come into play.

Part IV assesses how the law will shape the further development of the industry and the deployment of robots in it. It rejects broad calls for new kinds of regulation of AI and robotics, explaining that basic regulatory frameworks already exist, and argues that seeking to restrain new technologies that enhance labor productivity would be unwise in the extreme, repudiating the engine of economic growth and the advance of human welfare of the last two centuries. Part V assesses the effect of non-legal forces, such as concerns about nutrition, about the environment and about animal welfare, and Part VI recommends policy directions.

The article pays relatively little attention to robot use in slaughterhouses and packinghouses. These are industrial environments, and the challenges and possibilities for robotics in those environments are basically the same as in other industries. Cattle production, on the range, in confined feedlots, and on the highways, presents quite different challenges from the industrial settings of beef packers.

II. THE PATHWAY FROM LONG CATTLE DRIVES TO THE MARCH OF ROBOTS ONTO THE RANGE

The great cattle drives and the popular image of the American cowboy were products of new technologies of agriculture and transportation and shifts in the law of property.[10] After the Civil War, property law combined with railroad technology to give rise to the long cattle drives, which con-

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9. *See* SUSSKIND, *supra* note 6 (Other, more sophisticated, analysis carefully considers the equilibrium between the job-displacing effects of automation and the job-creation effects.); *see also* JONATHAN WALDMAN, SAM: ONE ROBOT, A DOZEN ENGINEERS, AND THE RACE TO REVOLUTIONIZE THE WAY WE BUILD (2020) (describing the multiple challenges faced by the designers of a robot to lay bricks and the only partially satisfactory results).

10. Perritt, *Rise and Fall, supra* note 1, at 364.

nected a huge oversupply of cattle in Texas with the growing demand for beef on the tables of the Midwest and Northeast.[11] The law allowed cattlemen free use of the public lands to pasture their cattle until they were ready for market and then to move them to railheads on the hoof, in herds of thousands.[12] As the railroads pushed west to railheads in thinly settled areas of Kansas, Nebraska, and Wyoming, such drives could connect to markets in the east. Later in the century, other technologies and property law realities brought the long drives to an end.[13] The steel-bladed plow made it easier to cultivate the prairie and use it for crops as well as for feeding livestock.[14] The windmill made it easy to pump water from underground aquifers to irrigate the newly plowed plains.[15] Barbed wire made it possible for farmers and ranchers alike to enclose sections of the plains, making it less feasible to drive cattle across them.[16]

The world of the twentieth century cowboy was shaped by other changes in technology pertaining to trucking and roadbuilding, decentralization in business practices, and relatively little by law.[17] In the twentieth century, dramatic improvement in motor vehicle technology gave rise to the refrigerated cattle truck, which, along with the good-roads movement, provided a much more flexible way of moving cattle from range to feedlot, from feedlot to slaughterhouse and from slaughterhouse to market than did the relatively rigid railroad infrastructure.[18] At the same time, agricultural exemptions from economic regulation of trucking[19] and similar exemptions from the laws promoting collective bargaining[20] allowed the industry to change to take advantage of the new technologies.

After the long cattle drives of the nineteenth century, technology, economics, and law disaggregated the job of the cowboy into specialties: (1) some cowboys now specialize in transporting cattle; (2) some specialize in controlling and feeding them in feedlots; and (3) some work with herds on the open range.[21]

Now, law, politics, and technology once again are shaping the future of the cowboy and his industry in the twenty-first century. The laws that shaped the cattle industry in the nineteenth century[22] and the laws from

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11. *Id.* at 372–74.
12. *Id.* at 396, 401.
13. *Id.* at 392.
14. *Id.* at 393.
15. *Id.* at 394.
16. Perritt, *Rise and Fall*, *supra* note 1, at 394–95.
17. *See* Perritt, *Twentieth Century Cowboy*, *supra* note 1, at 146, 149–50.
18. *Id.* at 160–70.
19. *Id.* at 191–96.
20. *Id.* at 196–201.
21. *Id.* at 185.
22. *See* Perritt, *Rise and Fall*, *supra* note 1.

which the cattle industry was largely exempt in the twentieth century were laws of general application, relating to property rights, economic regulation of transportation, and collective bargaining. The laws likely to channel the effects of new technologies in the cattle industry in the twenty-first century are different. They target the beef industry and seek to change its practices directly. Likewise, the technologies that revolutionized the work cowboys did in the nineteenth and twentieth centuries were general: the technologies of the railroad, the truck, the windmill, and the fence. The disruptive technologies for the cowboy of the twenty-first century are specific: they are the technologies of the robot, and more particularly, the technologies of a robocowboy.

The role of these technologies in the industry will be shaped by specific regulatory initiatives aimed at robots.

Economics dominated and channeled the legal and technological influences of the nineteenth and twentieth centuries. It will do the same in the twenty-first, pushing the more sophisticated forms of robocowboys to the margins and rendering bold ideas for regulation of robocowboys irrelevant.

III. FORCES SHAPING THE REST OF THE CENTURY

Projections for the future of other industries, including industrial manufacturing, include prominent roles for robots.[23] The same thing is true for warehousing associated with e-commerce and for transportation. A chorus of support exists for the idea that self-driving trucks will dominate the trucking industry.[24]

Most forecasts for the beef industry suggest incremental change, as cow-calf operators and feedlot owners tailor feeding and veterinary treatment to the conditions of individual animals, who can be identified more easily with cheap Radio Frequency Identification (RFID) implants or tags.[25] The forecasts also predict incremental adaptation to land-use pressures centered on scarcity and growing concerns about the environmental impacts of cattle raising. The forecasts predict that the great plains will continue to be

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23. *See* McKinsey & Co., Industrial Robotics (2019), https://www.mckinsey.com/~/media/mckinsey/industries/advanced%20electronics/our%20insights/growth%20dynamics%20in%20industrial%20robotics/industrial-robotics-insights-into-the-sectors-future-growth-dynamics.ashx (summarizing expectations for the future).

24. *See, e.g.*, Paul A. Eisenstein, *Millions of Professional Drivers Will Be Replaced by Self-Driving Vehicles*, NBC News (Nov. 5, 2017, 9:58 AM), https://www.nbcnews.com/business/autos/millions-professional-drivers-will-be-replaced-self-driving-vehicles-n817356.

25. *See* Univ. of Minn. Extension, *New Official Cattle ID Tags Will Use Radio Frequency Identification (RFID)* (Oct. 14, 2019), https://extension.umn.edu/beef-news/new-official-cattle-id-tags-will-use-radio-frequency-identification-rfid (describing rationale for requiring RFID tags on cattle).

the major cattle feeding area in the United States.[26] While feedlots will continue to be concentrated, cow-calf operations will remain decentralized.[27] Other prognosticators predict farms full of robots,[28] but the prognosticators are vague about the incentives to hire robots to herd cattle.

A. Technological Forces

The outlook for robocowboys Dakota, Montana, and Texas depends on the potential of their technologies to allow them to do what their human counterparts, Kirby, Bennington, and Nash, do and their relative wages to do it. Cowboys, human or robotic, operate on bovine psychology.

1. Bovine Psychology

Cattle behavior has evolved to protect the animals from predators. Two major components of this behavioral adaptation exist, which are the herd instinct and the flight instinct.[29] Individual cattle are more comfortable bunched together with others in a herd.[30] Predators are less likely to take on a herd of cattle than a single beef. Moreover, even if a predator attacks the herd, the probability of any particular animal being killed is inversely proportional to the size of the herd.

The flight instinct causes a beef to move away from anything it perceives as a possible predator. Cowboys, especially cowboys on horseback, qualify as possible predators. The flight instinct is triggered whenever a possible predator invades a beef's flight zone, an area defined by a particular distance that represents the cow's zone of comfort.[31]

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26. Michael L. Galyean et al., *The Future of Beef Production in North America*, ANIMAL FRONTIERS, Oct. 2011, at 29, 32, https://academic.oup.com/af/article/1/2/29/4638612.

27. *Id.*

28. *See* Khasha Ghaffarzadeh, *Agricultural Robots and Drones 2018-2038: Technologies, Markets and Players*, IDTECHEX, https://www.idtechex.com/en/research-report/agricultural-robots-and-drones-2018-2038-technologies-markets-and-players/578 (last visited July 17, 2020) (predicting market for small agricultural robots as large as $900 million to $2.5 billion by 2028 to 2038, with an inflection point for rapid growth in 2024).

29. JOHN MORGAN AND REBECCA DOYLE, COW TALK: UNDERSTANDING DAIRY COW BEHAVIOR TO IMPROVE THEIR WELFARE ON ASIAN FARMS 52 (2015).

30. *Id.*; *see* IOWA STATE UNIV., ANIMAL BEHAVIOR AND RESTRAINT: CATTLE, http://www.cfsph.iastate.edu/Emergency-Response/Just-in-Time/08-Animal-Behavior-Restraint-Cattle-JIT-HANDOUT.pdf (last visited July 17, 2019) (generally describing cattle behavior, including herd instinct).

31. Flight distances for cattle vary depending on the animals' experience with humans. Feeding cattle have small flight zones—ranging from four to twenty feet—compared with range cattle.

The flight zone is the minimum distance a beef can be from someone and still feel comfortable.[32] Invading the flight zone is the primary means of herding cattle.[33] The point of balance is a place off the animal's shoulder.[34] Placing oneself forward of this point causes the animal to move backwards; placing oneself back of this causes the animal to move forward.[35] Persuaders such as flags, plastic paddles, and sticks with plastic ribbons have largely replaced electric cattle prods.[36] Persuaders can be used to turn cattle by blocking their vision on one side—the side to which they are to be turned.[37]

The herd instinct and the flight instinct work together to enable cowboys to herd cattle. A cowboy invades an individual animal's flight zone, the animal moves away, and if it can see a herd, it moves so as to merge into the herd.[38] A cowboy at the front of the herd positions himself behind the lead cattle's trigger point and just inside its flight zone, causing the cattle to move forward. [39] Other cowboys on each side and behind the herd do the same thing with the animals on the edges of the herd. [40] The result is that the entire mass of the cattle moves in the desired direction.[41]

2. Where Cowboys Work

The popular image of the cowboy, fueled by hundreds of Western movies and advertisements for twenty-first-century products, shows him herding cattle from horseback.[42] Herding cattle continues to be central to cowboys'

32. *See What Is a Cow's Flight Zone?,* AG SAFETY AND HEALTH (May 17, 2019), https://ag-safety.extension.org/what-is-a-cows-flight-zone/ (reporting that flight zone diameter for range cattle may be as much as 300 feet).

33. *See* IOWA STATE UNIV., ANIMAL BEHAVIOR AND RESTRAINT: CATTLE, http://www.cfsph.iastate.edu/Emergency-Response/Just-in-Time/08-Animal-Behavior-Restraint-Cattle-JIT-HANDOUT.pdf (last visited July 17, 2019).

34. *Id.*

35. *Id.*

36. *See* Temple Grandin, *Using Prods and Persuaders Properly to Handle Cattle, Pigs, and Sheep*, DR. TEMPLE GRANDIN'S WEBSITE (last updated Oct. 2018), https://grandin.com/behaviour/principles/prods.html (arguing that electronic cattle prods should mostly be replaced with other persuaders).

37. *See* UNIV. OF TENN. EXTENSION, CATTLE BEHAVIOR AND HANDLING FACILITIES, https://extension.tennessee.edu/Sullivan/Documents/Ag%20Documents/Master%20Beef%20Producer%20Lessons/Chapter%2009%20-%20Cattle%20Behavior%20[Read-Only]%20[Compatibility%20Mode].pdf (last visited June 27, 2020) (describing and illustrating interaction of herd instinct and flight zone in moving cattle).

38. *See supra* notes 31–35 and accompanying text.

39. *See supra* notes 31–35 and accompanying text.

40. *See supra* notes 31–35 and accompanying text.

41. *See supra* notes 31–35 and accompanying text.

42. *See Cowboy Herding Cattle Images*, SHUTTERSTOCK, https://www.shutterstock.com/search/cowboy+herding+cattle (last visited June 27, 2020) (providing 2,524 stock images of cowboys herding cattle).

work, but they do it in three dramatically different settings: on the range, in feedlots, and in cattle trucks. Twenty-first century cowboys do it from Gator[43] ATVs and on foot as often as they do it on horseback, and they do it from semi-trailer truck-tractors. They also perform other functions: they distribute feed on the range, in smaller pastures, and in feedlots; they observe cattle, alert to signs of disease or injury; they deliver simple veterinary care; and they assist in the breeding of cows and birthing of calves.[44]

Their functions differ considerably depending on whether they work on the range, in pastures, in feedlots or on the highways. Some of the work of driving cattle that occupied much cowboy time in the nineteenth century now is performed by asphalt cowboys,[45] driving cattle trucks from farm to feedlot, feedlot to slaughterhouse, and slaughterhouse to market.

The basic functions of the open-range cowboy steering long cattle drives to Dodge City in the nineteenth century were divided into three distinct activities, which were performed in different places for different employers.[46] Superintendence of the early stages of cattle raising—breeding cows, helping them to have calves, and weaning the calves at the appropriate time—activities performed mostly by the cattle themselves on the open range with little cowboy supervision, are now performed by cow-calf operators.[47] They are distinct from feedlot operators and employees who perform the function of "finishing" the calves, feeding them from the point of weaning to their slaughter weight, activities once performed by herding the cattle onto good range grass on the open range, and now performed by feeding them a mixture of corn, silage, and other nutrients in feedlots.[48] This, in turn, is distinguished from transporting the cattle, a function performed in the nineteenth century by driving them on foot across expanses of open range, and now performed by independent owner-operator truck drivers hauling semi-trailers designed for cattle. Slaughtering and processing of the carcass-

43. *See Gator Utility Vehicles*, JOHN DEERE, https://www.deere.com/en/gator-utility-vehicles/ (last visited July 17, 2020).

44. *See 15 Places in the U.S. Where Cowboy Culture Is Alive and Well*, WIDE OPEN COUNTRY, https://www.wideopencountry.com/11-places-us-cowboy-culture-alive-well/ (last visited June 27, 2020) (describing modern job of cowboy and comparing to content of legend).

45. If an independent owner-operator cattle hauler deserves the badge of "asphalt cowboy," *see* SHANE HAMILTON, TRUCKING COUNTRY: THE ROAD TO AMERICA'S WAL-MART ECONOMY 135 (2008) (using term in chapter title), a self-driving cattle truck is a particular type of robocowboy.

46. *See* Perritt, *Rise and Fall*, *supra* note 1 at 380–87 (describing labor markets for nineteenth-century cowboys).

47. *See* U.S. DEP'T OF AGRIC. ET AL., COW CALF INDUSTRY MANUAL 8–9 (2012), https://www.aphis.usda.gov/animal_health/emergency_management/downloads/documents_manuals/cow-calf_industrymanual.pdf (describing cow-calf operations).

48. *See id.* at 9–10.

es never was the province of cowboys and continues to be performed in large centralized factories owned by a handful of beef packers.

3. How Do Robots Work?

Robots are machines that perform a set of interrelated tasks automatically, without the need for a human operator to prescribe specific movements.[49] Thus defined, robots are not new to the twenty-first century, or even to the twentieth. Automatic looms were introduced in the early nineteenth century. They wove cloth from spools of yarn, requiring operator intervention only when it was time to change a roll of yarn or to refill the bobbin on the spindle.[50] After the Civil War, they could change their own bobbins. By the end of the twentieth century, much factory machinery was automatic—stamping metal parts, extruding bottles from plastic, and packaging finished products—without the need for active human control.[51] Twenty-first-century robots differ from these predecessors in the range of activities they can perform and their mobility.

Robots, considered at a high level of abstraction, usually comprise several of the following interrelated subsystems. A *machine vision* subsystem allows the robot to see what it is doing and where it is going. A *grasping and placing* system, intended to function like a human hand, manipulates objects. A *navigation system* tells the robot where to go based on sensing and evaluating its environment. A *guidance system* accepts the commands from the navigation system and causes the robot to follow a course in two-dimensional space[52] commanded by the navigation system. A *propulsion system* delivers power to the wheels[53] as appropriate to execute commands from the guidance system.[54]

Almost all robots need good machine vision. The importance of other types of subsystems depends on whether the robots are stationary or mobile. Many factory robots are fixed in place. They do not need navigation, guidance, or propulsion systems. Machine vision and grasping and placing sub-

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49. *See Robot*, MERRIAM-WEBSTER, https://www.merriam-webster.com/dictionary/robot.

50. *See* Henry H. Perritt, Jr., *Job Training Mythologies*, 98 NEB. L. REV. 795, 823–24 (2020) (describing early mechanization of textile industry).

51. See Jonathan Tilley, *Automation, Robotics, and the Factory of the Future*, MCKINSEY & CO., (Sept. 7, 2017), https://www.mckinsey.com/business-functions/operations/our-insights/automation-robotics-and-the-factory-of-the-future#.

52. Three-dimensional, in the case of drones.

53. Or rotors and other control surfaces, in the case of drones.

54. Assuming that the robot has wheels on axles rather than legs, the propulsion system would impart torque to the axles in the x dimension causing wheels to rotate. It also would deliver torque along the Z axis to cause the axles to change their orientation, resulting in a turn.

systems are their essence,[55] allowing them to put a part in a hole and screw it in, to weld a seam in the body of a car, to place mortar on a brick and put the brick into its place in a wall, and to pick packages to fulfill e-commerce orders. Designing the grasping and placing subsystems to work well is the hardest part of developing an acceptable factory robot.[56] Robocowboys do not need to grasp or manipulate objects, but they do need accurate machine vision and quick and responsive navigation, guidance, and propulsion systems.

Autonomous robots and vehicles are different from remotely controlled ones. Originally, the term "robot" signified a high degree of autonomy,[57] but the term is used more broadly now to include remotely controlled machines, such as Cargill's "Cowboy Robot."[58] Remotely controlled machines are much easier to design and build than autonomous ones. In a remotely controlled system, the human operator can perform the more difficult perception tasks necessary for precise positioning and collision avoidance, while autonomous subsystems keep the vehicle upright and following a prescribed course, perhaps one defined by GPS coordinates or operator-commanded spacing from other objects designated by the operator. Remotely controlled machines are desirable to keep the operator out of harm's way resulting from tasks performed at considerable heights, such as tower inspection, or tasks performed in dangerous environments, such as mine inspection or cattle herding.

Remotely controlled machines, however, do not offer the same labor savings as autonomous ones. A human operator is necessary for a remotely controlled machine, and her compensation may be equal to or greater than that for an operator of a conventional equivalent such as a tractor, an ATV, or a horse.

The strength of the case for adopting either type of technology depends on a comparison of the costs and benefits of new technology versus old. In the case of remotely controlled machines, it is the benefit of risk reduction balanced against the additional cost of the remotely controlled robot. This may not be much greater than the cost of a conventional machine because of the relative simplicity of the technology of remote control. Conventional

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55. *See* Ashutosh Saxena et al., *Robotic Grasping of Novel Objects Using Vision*, 27 INT'L J. ROBOTICS RES. 157 (2008) (generally describing interaction between robotic vision system and grasping mechanisms).

56. Waldman, *supra* note 9.

57. *Robot: "A Machine Resembling A Human Being And Able To Replicate Certain Human Movements And Functions Automatically.,"* GOOGLE, https://www.google.com/search?q=definition+of+robot&rlz=1C5CHFA_enUS812US812&oq=definition+of+robot&aqs=chrome..69i57j0l5.2791j1j7&sourceid=chrome&ie=UTF-8 (last visited July 17, 2020).

58. *Meet the Robot That's Making Cattle Herding Safer*, CARGILL (Oct. 18, 2018), https://www.cargill.com/story/meet-the-cowboy-robot-thats-making-cattle-herding-safer (describing "remote-controlled robot").

systems increasingly use electronic, computer-aided controls, and the operator controls can be made remote from the machine by the simple addition of appropriate digital radio links.

Increasing levels of autonomy require at least proportionate increases in complexity and sophistication of sensors, control algorithms, servomechanisms, and hardware and software to tie them all together. Increasing complexity means more challenges in quality assurance and risk assessment. The result is substantially higher costs for more autonomous systems.

But fully autonomous systems provide a significant benefit: the elimination of the human predecessor of the autonomous robot. A straightforward comparison between the compensation of the predecessor and the cost of the robot makes the decision whether to substitute technology for labor straightforward.

Robocowboys need good machine vision and fast and adaptable navigation, guidance, and propulsion subsystems. They do not need particularly sophisticated grasping and manipulation subsystems. Accordingly, the following subsections develop machine vision, navigation, guidance, and propulsion concepts in more detail than grasping and manipulation concepts.

a. Machine vision

A robocowboy must "see" the cattle it is responsible for so that it knows where to go to herd them. An essential part of its robotic capability is machine vision. Machine vision depends upon pattern recognition. The robot must know what kind of pattern the image of a beef makes when it falls on the robot's optical sensor.

Machine vision, pattern matching, image recognition, and machine learning all are related in the following way: computers and their software see things through the technology of machine vision. Machine vision depends upon the computer's ability, through its sensors and its software, to recognize certain patterns—the edge of the road, the outline of a steer. Pattern matching requires the processing of many bits of data representing the state of pixels in a video sensor on which an image from the real world is projected by a camera.[59] The image projected on the sensor is represented by the state of many individual pixels, with the number of pixels determining the resolution of the sensor.[60] The state of all the pixels on the sensor at any point in time is conveniently represented by a vector of pixel values.[61] Pro-

59. *See What Is Machine Vision,* COGNEX, https://www.cognex.com/what-is/machine-vision/what-is-machine-vision (last visited June 27, 2020) (describing machine vision and explaining how it works).

60. *See id.* (describing digital image sensor).

61. *See* Daniel Shiffman, *Images and Pixels*, PROCESSING (2008), https://processing.org/tutorials/pixels/ (describing how pixels on an image sensor are processed by a computer).

cessing the vector values enables software to recognize edges—where pixels in adjacent rows discontinuously go from light to dark or vice versa or change color.[62] The algorithms can be taught to find the relevant edges by statistical analysis of a large number of examples containing photographs of the object, through machine learning.[63]

i. Pattern matching

Machine vision, like human vision, requires recognition of an object that is seen. Computers do this by matching the pattern of digital bits recorded on their sensors with the pattern of bits they know is associated with an object like a cowboy, a dog, a horse, or a cow.[64]

Pattern recognition is fundamental to all forms of machine perception.[65] A wireless text communication system must match the pattern of radio signals with known patterns of bits for alphanumeric characters, as in the American Standard Code for Information Interchange. Sonar systems must determine if the sound signals reflected from an object match those likely to be reflected by a gate cut in a fence. Other acoustical systems must listen for a particular type of "moo" uttered by a cow that has become separated from her nursing calf.[66] A touch sensor must be able to determine whether the hardness, elasticity, and inertia of an object match those of the hide of a calf, a rock, or a wooden fence. A visual perception system must be able to determine when the pattern of colors and light and dark areas detected by a light sensor or collection of light sensors represents the image of a steer.

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62. *See* RAMESH JAIN ET AL., MACHINE VISION 140–85 (describing logic of edge detection).

63. *See* Ankit Sachan, *Deep Learning Based Edge Detection in OpenCV*, CV-TRICKS.COM, https://cv-tricks.com/opencv-dnn/edge-detection-hed/ (last visited June 27, 2020) (describing how machine learning is used for edge detection).

64. Jason Brownlee, *A Gentle Introduction to Object Recognition with Deep Learning*, MACHINE LEARNING MASTERY (May 22, 2019), https://machinelearningmastery.com/object-recognition-with-deep-learning/ (explaining how machine learning is used to develop image recognition systems).

65. Robin Kallsen, *Lights, Camera, Algorithms: The Basics of Machine Vision Pattern Matching,* OMRON MICROSCAN SYSTEMS (Feb. 21, 2018), https://www.microscan.com/en-us/blog/post/lights-camera-algorithms-the-basics-of-machine-vision-pattern-matching-microhawk ("The first step in any machine vision task is pattern matching, i.e. locating an object within the field of view based on an expected arrangement of shape attributes like edges.").

66. *See* MÓNICA PADILLA DE LA TORRE ET AL., ACOUSTIC ANALYSIS OF CATTLE (BOS TAURUS) MOTHER–OFFSPRING CONTACT CALLS FROM A SOURCE–FILTER THEORY PERSPECTIVE (2015), https://animalstudiesrepository.org/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1022&context=acwp_asie (reporting on results of acoustical analysis of cow and calf calls, which distinctively represent different nursing conditions).

ii. Image recognition

Image recognition is a particular type of pattern matching, which focuses on the matching visible images rather than sound profiles or text strings.[67]

The sensors for machine vision—the basic hardware for image recognition—are digital cameras with flat sensors comprising tens of thousands or millions of light-sensitive pixels. The number of pixels determines the resolution of the image that can be captured; the more pixels, the higher the resolution.[68]

Most image recognition algorithms start with edge detection: determining where the boundary of an object is, represented by the sharpest contrast from light to dark.[69]

A simple example recognizes a square by comparing the state of pixels on a visual camera sensor with a pre-stored matrix of values. If many adjacent pixels in parallel columns are dark, forming two dark lines, these are edges (the sides). If many of the adjacent pixels in parallel rows connecting the columns at the corners are dark, they also are edges (the top and bottom). If the number of dark row pixels equals the number of dark column pixels, the camera is seeing a square.

Image recognition comprises the following: (1) *detecting* an image—locating it in a visual frame; (2) *identifying* it—determining whether it is a square, a steer, another robot, or a dog; and (3) *tracking* an image of that type in the frame.[70]

Any image recognition task can be accomplished either by encoding the necessary characteristics of the object to be recognized or by providing the system with a (very large) number of examples from which it can "learn." In most practical applications, neither is a trivial task. Objects must be recognized, not only when they are in some preestablished position with respect to the sensors, but also at arbitrary orientations. A two-dimensional representation of a cow is quite different when viewed from head-on than from the side, from the rear, or at an angle from above.

Additionally, useful image-recognition systems must recognize objects, not only in a fixed position, but also in motion. They also must be able to determine characteristics of the motion, such as direction, velocity, and ac-

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67. *See supra* notes 58–64 and accompanying text.

68. *See Image Resolution*, WIKIPEDIA, https://en.wikipedia.org/wiki/Image_resolution (explaining basics of digital imagery) (last visited July 17, 2020).

69. *See* JAIN ET AL., *supra* note 62, at 140–85.

70. *See* Evelyn Graveling, *A Closer Look at Object Detection, Recognition and Tracking* (Dec. 18, 2017) https://software.intel.com/content/www/us/en/develop/articles/a-closer-look-at-object-detection-recognition-and-tracking.html (describing the states of object recognition).

celeration. Detecting motion is simpler than recognizing the object itself; once the object is recognized, the system need only take a series of snapshots and calculate the vectors representing change in position from the previous snapshot. The rate of change in position is velocity, and the rate of change in velocity is acceleration, calculations that any first-year college student in physics knows how to make. Direction of movement is determinable from the values of the vectors.

Once the machine vision system on a robocowboy recognizes an object as a cow or steer, it must determine its distance and bearing from the robocowboy. The bearing can be determined from the angle that the camera is pointed with reference to the robot. Distance can be determined in any one of several ways. Sonar, LiDAR, or radar can determine distance exactly. Binocular cameras can determine the distance by computing depth perception angles. A monocular camera can compute approximate distance by comparing the spacing of the pixels that represent the edges of the animal on its sensor with a reference value for objects of a similar size. The closer together the pixels, the farther away the animal is.

This is a process that ordinarily takes place with multiple two-dimensional representations of space, although it is possible to construct algorithms that work with three-dimensional representations. Imagining how many subtle differences exist among all the two- or three-dimensional outlines of a steer that result from different camera angles, lighting conditions, and backgrounds gives one a sense of the magnitude of the challenge.

iii. Machine learning

A perfectly stationary object in the frame of a robot's optical sensor can be defined by programming in advance the coordinates of its edges on the sensor.[71] When the edges match statistically, the sensor is seeing the programmed object. By comparing its own coordinates with the preprogrammed coordinates of the object, the robot knows where the object is. Such a representation of reality might result in useful capability in a factory environment where robots and the object they work on can be fixed precisely in place. It would be of little use, however, for cattle herding, where both the cattle and the robocowboy herding them are moving around all the time. Likewise, it would be of little use for self-driving vehicles, where the appearance of the edge of the road, compared to the shoulder, varies considerably with the type of road, the design of road markings, the nature of surrounding terrain, and the lighting conditions and shadows.

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71. The explanations in this subsection are based on the author's experience programming computers, over a period of some sixty years.

Machine learning is a technology that sidesteps the need to program a robot in advance with the pixel coordinates representing a particular object such as a calf.[72] Machine learning does not depend upon knowledge engineering in the traditional sense of getting an expert to articulate rules for decision-making. It thus expands the boundary of automation's capabilities. This is true even for facial recognition. The language for describing faces is imperfect; Facebook's machine learning results are far superior.

Machine learning facilitates image recognition by allowing a programmer simply to present a series of images to the system with a specification that they do or do not contain the object whose image is to be learned. During such training, the algorithms discover for themselves what attributes of an image determine whether the target object is likely present.[73] Any machine learning system will function well in any domain where the goal can be identified clearly and there is lots of data. Determining whether the image of an animal shows a cat is a good example: the goal is clear—it either is or is not a cat. And an enormous store of data is available, comprising all the pictures of animals and other objects that can be made available to a machine learning system.

Image recognition algorithms are developed through a machine learning process in which thousands of real-world images portraying the object to be recognized are processed.[74] The data set containing the images includes

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72. *See supra* notes 58–64 and accompanying text.

73. Kallsen, *supra* note 65. *See PyTorch*, WIKIPEDIA, https://en.wikipedia.org/wiki/PyTorch (last visited July 8, 2020) (describing machine-learning library with Python interface used by Uber and others to automate deep learning to implement computer vision applications); PYTORCH, pytorch.org (last visited Oct. 17, 2020) (providing access to PyTorch programming tools; reporting that PyTorch runs on all major cloud computing platforms). The PyTorch tutorials page includes an image of a cowboy on horseback as an illustration of an object detection problem. PYTORCH, pytorch.org/tutorials (last visited Jan. 26, 2020). *See also* Lex Fridman, *Deep Learning State of the Art (2020)—MIT Deep Learning Series*, YOUTUBE (Jan. 10, 2020), https://www.youtube.com/watch?v=0VH1Lim8gL8 (reporting at minute 13:22 on importance of TensorFlow and Pytorch development tools for deep learning innovation). Machine learning is like Darwinian evolution.

74. *See* Pulkit Sharma, *A Beginner-Friendly Guide to PyTorch and How It Works from Scratch*, ANALYTICS VIDHYA (Sep. 17, 2019), https://www.analyticsvidhya.com/blog/2019/09/introduction-to-pytorch-from-scratch/?utm_source=blog&utm_medium=pytorch-tutorial (providing basic tutorial on how to use 60,000 images in a training set and 10,000 images in a test set to train a neural network to recognize one of ten clothing types, such as a dress, a coat, or a sneaker). Each image in either a training set or a test set can be represented as an i x j array of pixel values, with each value ranging from, say, 0 to 255. Each image is thus an i x j array of integers labeled with its subject matter—coat sandal, ankle boot, or trouser in the TensorFlow tutorial, *Basic Classification,* TENSORFLOW TUTORIAL, https://www.tensorflow.org/tutorials/keras/classification. An analytical process not unlike multiple regression analysis interactively fits a tensor (an n-dimension vector) to the training data. *See generally* Rajarshi Guhaniyogi et al., *Bayesian Tensor Regression*, 18 J. MACHINE LEARNING RES. 1 (2017), http://www.jmlr.org/papers/volume18/16-362/16-362.pdf_(applying

pictures from different camera angles, with different lighting levels and shadow patterns, different colors, and different background images and textures. Each image is labeled with its subject matter. The machine learning algorithm records patterns of lightness and darkness in different colors and tags them with the label of the name of the object in the photograph.

The algorithm takes the edges found on the sensor raster and iteratively compares them with the edges found in the training images. A variety of well-developed equations facilitate the statistical analysis involved in the comparisons.[75] Image recognition can be improved by reframing the image, so that the object of interest appears in a standard region of the frame (usually the center) and at a standardized size.[76] Eventually, given enough samples, the software fixes a digital pattern that represents a single stray, another robot, a dog, or a herd of cattle. Performance measures include the percentage of objects tagged correctly, sensitivity—the percentage of objects not recognized, and selectivity—the percentage of images tagged as representing the object that do not in fact contain an image of the object.

Most readers are familiar with Facebook's facial recognition. When one uploads a new photograph to one's Facebook page, Facebook software assists one in tagging faces in the new photograph with the names of the subjects by suggesting names when one clicks on the face. These results are enabled by Facebook's enormous store of existing photographs against which it has applied machine learning techniques to learn what their subjects look like.[77] It is the author's experience that Facebook guesses right at least

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Bayesian linear regression techniques to tensors). The result is a tensor representing the object, say, a sneaker, in the TensorFlow example.

75. *See* S.M. Konishi et al., *Statistical Edge Detection: Learning and Evaluating Edge Cues*, 25 PATTERN ANALYSIS AND MACHINE INTELLIGENCE 29 (2003), http://www.cs.jhu.edu/~ayuille/pubs/ucla/A174_skonishi_PAMI2003.pdf (discussing different statistical techniques for recognizing edges); Stamatia Giannarou & Tania Stathaki, *Novel Statistical Approaches to the Quantitative Combination of Multiple Edge Detectors*, INT'L CTR. FOR ADV. INTERNET RES., LNCS 4141 181, 184 (2006) (explaining importance and challenges of edge detection in image recognition systems); Deva Ramanan et al., *Building Models of Animals from Video*, https://www.cs.cmu.edu/~deva/papers/animals_journal_draft.pdf (last visited Oct. 17, 2020) (explaining digital techniques for tracking, identifying, and detecting animals); Andy Rosales Elias et al., *Where's the Bear?—Automating Wildlife Image Processing Using IoT and Edge Cloud Systems*, UNIV. OF CALI. (Oct. 2016), https://www.cs.ucsb.edu/sites/default/files/docs/reports/tr.pdf (explaining image recognition techniques).

76. *See* Method for Reframing Images of a Video Sequence, and Apparatus for Reframing Images of a Video Sequence, European Patent No. EP2680219A1 (issued Jan. 1, 2014); Method for Image Reframing, U.S. Patent No. 20120063685A1 (issued Dec. 17, 2013).

77. *See Deepface*, WIKIPEDIA, https://en.wikipedia.org/wiki/DeepFace (describing Facebook's DeepFace as "employ[ing] a nine-layer neural network with over 120 million connection weights," organized as a siamese network, "trained on four million images uploaded by Facebook users"; reporting Facebook Research team claim that DeepFace "reaches an accuracy of 97.35%") (last visited July 17, 2020). tf.keras is a TensorFlow/Python application

half the time. (Facebook claims a much higher accuracy.) This illustrates a considerable achievement of the machine learning techniques for image recognition, considering how many different faces there are in the world and how many variations there are in the way they are portrayed in amateur photographs.

Cattle, as well as people, can be recognized. It may not be important to recognize a particular animal, but it is important to recognize an animal that has strayed from the herd. A robocowboy does not need to know a specific animal, but it must be able to recognize a cow, as distinct from a stump, a bush, another robocowboy, or a human cowboy, mounted or on foot. These basic pattern matching tasks can be replicated at higher levels of aggregation so that herds, as well as individual steers, can be recognized. Similarly, the direction and speed of movement of the herd can be determined.

Texas, the cattle truck robot, can infer from a number of example images what the edge of a road looks like. The training images would include images of interstate highways with solid white stripes marking the lanes, some with dashed marking lines, some with solid, some with different colors and different designs of lines marking inter-lane boundaries, compared with those marking the edge of the road, roads with paved shoulders separated from travel lanes by distinctive lines, city streets, in which the boundary of the road is marked by lines often indistinct and dirty, city streets with road boundaries defined only by curbs, rural paved roads without any kind of marking to separate shoulder from road, unpaved paths, and so on.

After the presentation of a sufficient number of image examples, the software can determine what the boundary of a road looks like, with reasonable reliability. This is if the examples do not deviate from each other too much in the imagery of the road boundary.

The phrase "machine learning," while an accurate description of this process, can easily be wildly misunderstood. The process of machine learning just described is not the same thing at all as saying to a robotic vehicle, "I'll take you for a drive along the best route, and then you can try it for yourself." Human drivers learn that way; machines do not, although the tools to teach computers in the way they learn are proliferating.[78] The type of learning involved when a fast computer processes 10,000 images of es-

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program interface that facilitates building and training deep learning models. It is based on DeepFace. *The Sequential Model*, TENSORFLOW GUIDE, https://www.tensorflow.org/guide/keras (last visited July 17, 2020).

78. *See* Amazon, *AWS Deep Learning AMIs*, AWS, https://aws.amazon.com/machine-learning/amis/ (describing Amazon's free tools to implement deep learning through Amazon's cloud computing resources) (last visited July 17, 2020).

sentially the same object in different settings is not the same thing as holistic human learning.[79]

What is achievable through machine learning depends on the amount and quality of data, the teaching images presented to the machine-learning algorithm. Tens of thousands of images are needed to get decent results even for the simplest systems. Tesla is improving the quality of its automobiles' autopilot systems by constantly adding to its data store. Every vehicle sends large quantities of data from its driving back to Tesla engineers.[80] For example, the ability of a Tesla to navigate safely and promptly through complex intersections is being improved by data that allows the Tesla engineers to correlate the images of all the details of intersections with those instances in which the driver takes over. A driver takeover is an indication that something went wrong. Eventually, Tesla will use these data to teach the vehicles how to avoid the situations where drivers take over.[81] John Deere similarly is improving the quality of its autonomous tractor prototypes by collecting hundreds of thousands of images from fields and using them as teaching examples.[82]

> "Deep learning is great at interpolating conditions between what it knows; it is not good at extrapolating to situations it hasn't seen. And in agriculture, you always feel that there is a set of conditions that you haven't yet classified." . . . "We are one of the largest users of cloud computing services in the world[.] . . . We are gathering 5 to 15 million measurements per second from 130,000 connected machines globally.

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79. *See* KIMBERLY NEVALA, THE MACHINE LEARNING PRIMER 6 (2017), https://www.sas.com/content/dam/SAS/en_us/doc/whitepaper1/machine-learning-primer-108796.pdf (eBook published by SAS, summarizing limitations of machine learning: does not result in autonomous creativity, does not result in developing new hypotheses from facts, cannot determine "new way to respond to emerging stimuli"; limited to programmed hypotheses about datasets machine is exposed to). SAS is a major software and computer services vendor. *See generally* Tommi Jaakkola et al., *6.867 Machine Learning*, MIT (2006), https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-867-machine-learning-fall-2006/ (noting that statistical inference "provides the foundation" for most machine learning; listing classification and linear regression, boosting, support vector machines, hidden Markov models, and Bayesian networks as course topics). The course website provides access to instructor's notes and problem sets and answers. *See also* Tommi Jaakkola, *Machine Learning with Python: From Linear Models to Deep Learning*, EDX, https://www.edx.org/course/machine-learning-with-python-from-linear-models-to (last visited Oct. 17, 2020) (describing online course using Python, a programming language quite similar to Swift, the language used in this article, to introduce machine learning).

80. Brittany Martin, *Your Tesla Is Watching—and Recording—You All the Time*, LA MAG. (Mar. 14, 2019), https://www.lamag.com/citythinkblog/tesla-recording-data-privacy/ (describing Tesla's real-time collection of data from vehicles).

81. *See Autopilot*, TESLA, https://www.tesla.com/autopilotAI (describing use of machine learning to improve Tesla's autopilot system) (last visited June 27, 2020).

82. *See infra* note 116 and accompanying text (describing John Deere robot development activities).

> We have over 150 million acres in our databases, using petabytes and petabytes [of storage]. We process more data than Twitter does."[83]

The same kind of thing is possible with robocowboys, and the learning necessary for robocowboys may be less daunting than the learning necessary for field robots, which must identify crops and surface conditions, as the preceding quote indicates. Practical limitations are, first, the modest number of photographs of cattle being herded, and second, that the ability of robocowboys to get better with experience depends upon not only collecting data from their environment, but also sending it to a place where it can be combined with other data from other robocowboys, following the Tesla example.

b. Navigation systems

Navigation refers to the calculation of destination and the position of a vehicle.[84] Its results are necessary inputs to guidance and propulsion systems. The navigation system knows where things are; the guidance system determines how to get to a destination.

i. Cartesian navigation

Navigation requires a system for representing the location of points in space. The Cartesian or rectangular coordinate system is the standard way of doing that.[85] The Cartesian system for navigation on the Earth's surface uses latitude—degrees above or below the equator—and longitude—degrees east or west of a reference meridian—for that purpose.

Inertial navigation permits vehicles to calculate their Cartesian positions, and thus to navigate, without any external references. Such navigation systems for robots have been highly developed for fifty years, permitting Intercontinental Ballistic Missiles (ICBMs) to perform their missions with-

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83. Tekla S. Perry, *Want a Really Hard Machine Learning Problem? Try Agriculture, Says John Deere Labs*, IEEE SPECTRUM (Oct. 4, 2019), https://spectrum.ieee.org/view-from-the-valley/robotics/artificial-intelligence/want-a-really-hard-machine-learning-problem-try-agriculture-say-john-deere-labs-leaders (second alteration in original) (quoting Julian Sanchez, John Deere's director of precision agriculture, and Alexey Rostapshov, John Deere's head of digital innovation; generally reporting on interviews with heads of John Deere Labs as saying that classification problems for agricultural robots are overwhelming; giving examples of different varieties of corn, with kernels that appear in different shapes and colors).

84. *See generally Navigation Systems*, WIKIPEDIA, https://en.wikipedia.org/wiki/Navigation_system (last visited July 19, 2020).

85. *See Rectangular and Polar Coordinates*, NASA, https://www.grc.nasa.gov/www/k-12/airplane/coords.html (last visited July 19, 2020) (explaining Cartesian or rectangular coordinate system used for navigation and comparing polar or vector coordinates).

out anyone on board,[86] permitting military and civilian drones to perform their missions, and enabling self-driving cars and trucks to perform well enough to approach regulatory and public acceptance.

Inertial navigation systems, however, drift and become less accurate with the passage of time; inexpensive internal navigation systems are accurate for only a few seconds without some means of external reference to update them.[87]

ii. External references

The most common external reference for ground and air vehicles is GPS. GPS receivers on the vehicle acquire signals from multiple GPS satellites in Earth's orbit and use triangulation to calculate vehicle position with an accuracy of a few feet.[88]

GPS navigation can be made more accurate by integrating its data with data from camera, sonar, LiDAR, and radar sensors. One patent application describes the navigational challenges for autonomous vehicles as follows, explaining the strengths and weaknesses of different kinds of sensors:

> For an autonomous vehicle to stay in a lane, the localization requirements are in the order of decimeters. GPS alone is insufficient and does not meet these requirements. In today's production-grade autonomous vehicles, critical sensors include radar, sonar, and cameras. Long-range vehicle detection typically requires radar, while nearby car detection can be solved with sonar. Radar works reasonably well for detecting vehicles, but has difficulty distinguishing between different metal objects and thus can register false positives on objects such as tin cans, mailbox, etc. Also, radar provides little orientation information and has a higher variance on the lateral position of objects, making the localization difficult on sharp bends. The utility of sonar is both compromised at high speeds

86. These technologies were in use by the United States Navy and the United States Air Force in the mid-1960s when the author was an undergraduate at MIT, working on them. *See generally* ROBERT D. BRAUN ET AL., ADVANCES IN INERTIAL GUIDANCE TECHNOLOGY FOR AEROSPACE SYSTEMS 1–2 (2013), https://engineering.purdue.edu/RDSL/aiaa-guidance-navigation.pdf (discussing the evolution of inertial navigation system technologies in aeronautics). The military ICBMs relied on inertial navigation systems, which did not need sensors to collect external data in-flight. They only needed extremely accurate position data at the beginning of the flight and extremely accurate position data about the target.

87. OLIVER J. WOODMAN, UNIV. OF CAMBRIDGE COMP. LAB., TECH. REPORT NO. 696: AN INTRODUCTION TO INERTIAL NAVIGATION (2007), https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-696.pdf (describing internal navigation system components, pervasive problem of drift, and possible mitigating approaches).

88. *See The Global Positioning System*, GPS.GOV, https://www.gps.gov/systems/gps/ (last visited July 19, 2020) (providing overview of GPS); *GPS Accuracy*, GPS.GOV, https://www.gps.gov/systems/gps/performance/accuracy/ (last visited July 19, 2020) ("GPS-enabled smartphones are typically accurate to within a 4.9 m (16 ft.) radius under open sky.")

and, even at slow speeds, is limited to a working distance of about two meters.[89]

LiDAR has an advantage over cameras at short ranges.[90] When objects are nearby, the sensing subsystem should increase the frequency of updates, because even small movements may create the risk of a collision. If a camera takes more frequent images of the nearby environment, the amount of processing necessary increases to the point that otherwise adequate computing power becomes inadequate. An image processing system activated by digital cameras must process every pixel in the raster, and then must perform complex calculations to estimate distances from two stereoscopic images or from measuring the distance between pixels and comparing them to a reference value.

A LiDAR system does not suffer from that computational disadvantage.[91] The LiDAR beam can be directed at that part of a frame that is of greatest interest, while the processing load is limited to processing information about the point at which the beam is aimed.[92] LiDAR also inherently provides information about distance as part of its basic computations of the time its beams take to travel out and back, to and from the part of an object that reflects it. The resolution obtainable from LiDAR systems is considerably less than that obtainable from digital cameras, however.[93]

An inertial measuring unit (IMU) measures changes in position without the need for any external signals from GPS satellites or other sources.[94] An IMU contains an accelerometer for each axis. Each accelerometer provides data on quantifying acceleration along the axis to which it is oriented. IMU software then integrates those values to determine velocity and integrates again to determine the position on each axis. IMUs and GPS receivers typically work together. The accelerometers tend to drift and thus produce progressively less accurate position readings. The GPS signal is used periodically to recalibrate the IMU, which in the short term can provide updated position information whenever the GPS signal is lost.

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89. Quadocular Sensor Design in Autonomous Platforms, U.S. Patent No. 10,192,113 (describing system with multiple cameras and auxiliary sensors for positional awareness for improved machine speed and accuracy).

90. *See generally* Varuna De Silva et al., *Robust Fusion of LiDAR and Wide-Angle Camera Data for Autonomous Mobile Robots*, SENSORS (Aug. 20, 2018), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6112019/pdf/sensors-18-02730.pdf (describing and illustrating techniques for combining (fusing) imagery from wide angle cameras and LiDAR systems).

91. *Id.* at 9.

92. *Id.*

93. *Id.* at 2.

94. *See generally Inertial Measurement Unit*, WIKIPEDIA, https://en.wikipedia.org/wiki/Inertial_measurement_unit (last visited July 19, 2020).

iii. Object self-reporting: individual cattle tracking systems

Precise navigation can be improved by incorporating self-reporting by objects with which a vehicle must interact. The National Aviation System now requires most aircraft to be equipped with Automatic Dependent Surveillance Broadcast (ADS-B) transponders, which constantly broadcast the position and altitude to other aircraft.[95] In agriculture, low-cost RFID devices permit individual animals or fixed objects in feedlots to broadcast their positions to robots.[96] Use of ultra-high frequency (UHF) frequencies on newer models increase the range at which robots can receive signals.

c. Guidance and propulsion systems

Guidance subsystems take the output of navigation systems and calculate changes in vehicle position and orientation necessary to follow the course to be navigated.[97]

Most farm vehicles use drive-by-wire technology, in which commands for steering, propulsion, and braking travel as electronic signals rather than mechanical forces. Vehicles employing this technology have one or more CAN[98] buses which carry the command signals to the steering, propulsion, and braking apparatus and data from sensors back to the central processing unit. CAN bus is like Ethernet, in that it is a standard at Layer 2 of the Open Systems Interconnection (OSI) stack, which specifies how packets are defined, how they are addressed and how contention for the circuit is arbitrated.[99] They do not, however, standardize how data is expressed in those protocols. The standards at the top of the OSI stack are proprietary, but most of the higher layer protocols are CAN-based, meaning that they are intended to work through a CAN bus.

A robocowboy designer can build his robot on top of off-the-shelf vehicle systems on the market that already have CAN buses and specifications

95. 14 C.F.R. § 91.225 (2020).

96. *See USDA Mandates RFID Livestock Tracking*, ATLASRFIDSTORE, https://www.atlasrfidstore.com/usda-mandates-rfid-livestock-tracking/ (last visited July 19, 2020) (describing technology and USDA mandate). On October 25, 2019, USDA suspended its mandate for RFIDs because of the regulatory burden. APHIS, *APHIS Statement on Animal Disease Traceability*, USDA (2019), https://www.aphis.usda.gov/publications/animal_health/traceability.pdf (reporting reliance on incentives to deploy RFID, instead of mandates).

97. *See generally Guidance Systems*, WIKIPEDIA, https://en.wikipedia.org/wiki/Guidance_system (last visited July 19, 2020).

98. Controller Area Network.

99. *See* Keith Shaw, *The OSI Model Explained: How to Understand (and Remember) the 7-Layer Network Model*, NETWORK WORLD (Oct. 22, 2018, 11:17 AM), https://www.networkworld.com/article/3239677/the-osi-model-explained-how-to-understand-and-remember-the-7-layer-network-model.html (explaining Layer 2 of OSI model).

for the commands necessary to achieve particular results from motors, brakes, and steering devices.

The designer then need not worry about the servomechanisms that execute guidance and propulsion commands; he can focus his attention on writing the algorithms necessary to translate navigation inputs into guidance directives.

d. State of the art

The technology for Texas, the self-driving cattle truck, is already in the marketplace. Patents have been granted for autonomous truck technology.[100] The technologies required for self-driving trucks are the same for sensors, position monitoring, and navigation as for any self-driving vehicle. Technologies for vehicle handling, however, must reflect the dynamics of the particular vehicle, including weight, center of gravity, resistance to tipping, turning radius, and body rigidity.

A study by the European Patent Office showed that patent applications related to self-driving vehicle technology increased by more than 330% from 2011 to 2018, a growth rate more than twenty times that for patent applications in general.[101] Of the patent applications for automotive technology, some forty-four percent related to perception, analysis, and decisions, while just over sixty-three percent related to vehicle handling.[102]

Inventions for which patents were sought included "long-range radar for adaptive cruise control, emergency braking, pedestrian detection, collision avoidance, . . . Lidar for environment mapping, . . . cameras for lane departure . . . control [and] traffic sign recognition," GPS vehicle localization, route selection and navigation, "traffic jam autopilot," and off-road driving navigation for winding roads and poor road conditions.[103]

The technology for Montana, the feedlot robot, and Dakota, the range robot, is not as far along. Primitive robots for herding are in operation in Australia.[104] The technology exists for building on these pilot projects. In-

100. *See* Autonomous Delivery Platform, U.S. Patent No. 9,256,852 (issued Feb. 9, 2016) (patent for self-driving package-delivery vehicle, using a box truck as the example).

101. EUROPEAN PATENT OFFICE, PATENTS AND SELF-DRIVING VEHICLES 9 (2018), http://documents.epo.org/projects/babylon/eponet.nsf/0/65910DF6D3F02057C125833C004DB1E6/$File/self_driving_vehicles_study_en.pdf.

102. *Id.* at 10.

103. *Id.* at 59 (summarizing patent subject matter).

104. Bonnie Burton, *Robot Cowboys Get Cows Moooving on the Range,* CNET (Nov. 20, 2013, 6:00 AM), https://www.cnet.com/news/robot-cowboys-get-cows-moooving-on-the-range/ (describing Australian robot designed to herd twenty to one hundred cattle from field to gathering point such as dairy; costing $1 million; reportedly capable of additional duties such as "surveillance, surveying, soil sampling, security, graze management, and monitoring calving); Adele Peters, *The Last Cowboy Standing Is Going to Be This Cattle-Herding Robot*,

deed, off-the-shelf components exist for performing most of the necessary tasks.[105] A robocowboy designer merely needs to select what he needs by way of sensors and servomechanisms and pattern matching algorithms and integrate them into a useful machine.[106] That is the hard part. It's one thing to identify a herd of cattle, comprising fifty animals, with the nearest one fifty feet away and the farthest one two hundred feet away, and to know that they are moving generally from left to right, but a robocowboy needs to know what to do about it, if anything. That requires programming domain-specific knowledge and cowboy expertise into the computerized control systems of the robot.

Image capture systems abound,[107] as do systems for controlling robots in challenging terrain.[108] Pattern-matching for the beef industry has been refined to the point that individual cows of specific breeds can be recognized from overhead imagery of herds.[109] Robots are being tested that moni-

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FAST COMPANY (July 25, 2016), https://www.fastcompany.com/3062041/the-last-cowboy-standing-is-going-to-be-this-cattle-herding-robot (describing "Swagbot," a wheeled device for herding cattle; acknowledging that it tends to scare the cattle; providing a video showing operation of what appears to be little more than remotely controlled small tractor).

105. *See Create a People Counter Solution*, INTEL, https://software.intel.com/en-us/iot/reference-implementations/people-counter-system (last visited July 19, 2020) (demonstration of machine vision system that recognizes individual people and crowds). A people recognizer and counter could easily be adapted to become a cattle recognizer and counter. *See also Machine Vision Sensor Review*, FLIR, https://www.flir.com/landing/iis/machine-vision-camera-sensor-
re-
view?creative=358011392855&keyword=machine%20vision%20camera&matchtype=e&network=g&device=c&gclid=CjwKCAjwtO7qBRBQEiwAl5WC22Y2I378CzT4SI3vpYKBCYsCCV2m8iDuC0adR_iF-jhIfJEFHtXR1BoCdp8QAvD_BwE (last visited July 19, 2020) (listing and describing machine-vision camera models); YDLIDAR, https://www.ydlidar.com/index.html (last visited July 19, 2020) (webpage for vendor of LiDAR position sensor components); *Ultrasonic Range Finders*, ROBOTSHOP, https://www.robotshop.com/en/ultrasonic-range-finders.html (last visited July 19, 2020) (listing dozens of less-than $100 sonic sensors).

106. *See* Isaac Maw, *Eye Spy: The Basics of Robot Vision Systems*, ENGINEERING.COM (July 16, 2018), https://www.engineering.com/AdvancedManufacturing/ArticleID/17286/Eye-Spy-The-Basics-of-Robot-Vision-Systems.aspx (explaining one-, two-, and three-dimensional robot vision systems; emphasizing need to understand what robot has to do).

107. *See, e.g*, Image Capture System, U.S. Patent No. 10,334,230 (describing system and computer-implemented method for tracking objects in three dimensions).

108. *See, e.g.*, Omnidirectional Wheeled Humanoid Robot Based on a Linear Predictive Position and Velocity Controller, Patent No. 10,293,486; Quadocular Sensor Design in Autonomous Platforms, U.S. Patent No. 10,192,113 (describing system with multiple cameras and auxiliary sensors for positional awareness for improved machine speed and accuracy).

109. *See* William Andrew et al., *Automatic Individual Holstein Friesian Cattle Identification via Selective Local Coat Pattern Matching in RGB-D imagery*, 2016 I.E.E.E. INT'L CONF. ON IMAGE PROCESSING 484 (2016), https://ieeexplore.ieee.org/document/7532404 (describing system for recognizing individual cattle from overhead images); CHENG CAI & JIANQIAO LI, CATTLE FACE RECOGNITION USING LOCAL BINARY PATTERN DESCRIPTOR (2013),

tor cattle health[110] and decide on appropriate feed content and feeding frequency.[111]

Data sets to be used in this machine learning are available from university laboratories at Carnegie Mellon and MIT, and from social media networks such as Google, Amazon, and Facebook.[112] Not every subject matter is covered by these existing data sets, of course, and it is likely that robocowboy enterprise would have to supply some of its own photographs, or at least supplement available data sets with its own imagery.

Basic algorithms for machine learning associated with image recognition are available in off-the-shelf software, but a typical robot designer must adapt the algorithms to the specifics of his own application.

Theoretically, machine-learning-powered image recognition techniques could be used to teach a robocowboy how to herd cattle simply by watching human cowboys doing it. A robocowboy engineer could build a model based on the rules similar to those expressed in the Python programs presented in this article.[113] Then, he could use machine learning techniques with video exemplars to beef up—to refine—the rules. Imagine a machine learning system that presents thousands of images of a steer reacting to the approach of a cowboy. It is plausible that the machine eventually would learn about the flight zone phenomenon.

That would be possible, however, only with a sufficient stock of cowboy herding imagery. This stock of teaching images would need to be much larger than the stock of images used to teach robots to recognize still photographs. Motion introduces many more ambiguities into photographs that the algorithm must resolve in real time. Imparting that capability requires much more extensive teaching. Current examples in which a human worker teach-

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https://ieeexplore.ieee.org/document/6694369; WILLIAM ANDREW ET AL., VISUAL LOCALISATION AND INDIVIDUAL IDENTIFICATION OF HOLSTEIN FRIESIAN CATTLE VIA DEEP LEARNING (2017), http://openaccess.thecvf.com/content_ICCV_2017_workshops/papers/w41/Andrew_Visual_Localisation_and_ICCV_2017_paper.pdf (workshop paper describing how pattern matching works).

110. Alice Klein, *Robot Ranchers Monitor Animals on Giant Australian Farms*, NEW SCIENTIST (May 20, 2016) (reporting on trials of robot designed to check on cattle welfare and health on large Australian farm).

111. U.S. Patent Application No. 20050211174A1 (filed Apr. 11, 2005) (system for refining decisions about how long to feed cow-calf and feedlot cattle based on MRI images). The application explains how the invention can aid specific decisions at cow-calf, feedlot, and processing stages of production. System for Carrying Out and Managing Animal Feedlot Operations Using Coordinate Acquisition Techniques, U.S. Patent No. 6,032,084 (issued Feb. 29, 2000) (system for improving prior art in computerized feedlot systems, in part by using individual animal identification on portable device to dispense correct rations of food).

112. *See, e.g.*, *Datasets,* MITOPENCOURSEWARE: MASS. INSTITUTE OF TECHNOLOGY https://ocw.mit.edu/courses/sloan-school-of-management/15-097-prediction-machine-learning-and-statistics-spring-2012/datasets/ (last visited Oct. 28, 2020).

113. *See infra* Part III.A.4.c.ii.c and Appendix.

es a robot by going through the motions of the job with it present easier challenges because factory robots and their teachers do their jobs from a fixed position or within a very limited range of motion. Furthermore, the robocowboy environment is one in which movements must be quick, frequently altered, and linked tightly to what the cowboy sees from second to second. That is very different from the factory environment where almost everything is fixed except the robot and its teacher.

A robot developer is unlikely to have access to anything close to a sufficient stock of video recordings showing human cowboys herding cattle. Of course, a robot developer could commission new videos by working with ranchers to equip their cowboys with cameras—something like a GoPro camera—linked to a GPS device that would provide positional information as part of the video track. Eventually, the stock of video collected in this manner might become sufficient to serve as a useful robot teaching tool. Whether the commercial promise of the resulting robocowboy would justify the expense of collecting these data is a question considered in section V.B.

It is difficult to get the performance of image recognition systems that operate in open space better than ninety-five to ninety-nine percent of the time. This seems high, until one considers that the designer of a robocowboy must deal with the one to five percent of the times the robot is stumped and does not know what it is seeing. The robot must behave safely when that happens. Usually, that means it stops and waits for human intervention.

The acceptability of this level of performance depends on the acceptability of a human cowboy occasionally stopping and saying, "I don't know what to do." Even the most inexperienced and incompetent human cowboy usually can do better than that: figuring out something useful, even if it is not exactly the right thing.

The beef industry is attracting the attention of inventors and of the farm equipment industry. Some inventions relate to robotic touch[114] and to measuring animal temperature.[115] A 2001 patent granted to William C. Pratt[116] purports

> to address the broader need for a system and method for managing all aspects of the care, feeding, and marketing of cattle in a feedlot, on an individual animal basis if desired, from the time of their arrival to the time of their shipment for slaughter, for optimum feed and drug efficiency, animal health, animal performance, and profit to the feedlot producer.

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114. Simultaneous Kinematic and Hand-Eye Calibration, U.S. Patent No. 10,0768,42 (describing "machine vision systems and methods for simultaneous kinematic and head-eye calibration" for robots that need to handle objects).

115. Temperature-Sensing System for Cattle, U.S. Patent No. 4,865,044 (describing device for transmitting temperature of cow and cow's ID once embedded in cow).

116. Cattle Management Method and System, U.S. Patent No 6,318,289.

The application reviews the prior art represented by earlier feedlot patents.[117] Vendors actively advertise software to monitor cattle feeding.[118]

Major farm equipment vendors are ramping up their work on robotics.[119] Most of their work focuses on field robots. For them, the classification problems are more difficult than for robocowboys because recognizing different varieties of crops at different stages of maturity is more difficult than recognizing a bull, cow, or calf. On the other hand, the navigation problems for robocowboys are more difficult than for field robots. Field robots mostly follow crop rows; robocowboys must follow the unpredictable movements of cattle.

The current state-of-the-art robot technology suggests that robots can be made to do cowboy work as explored more specifically in Subsection 4—in other words, robocowboys may be technologically feasible, but the cost of educating them may be enormous. Section V.B considers whether they are economically feasible, in light of the engineering effort required.

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117. *Id.*, at "Known Methods and Systems Relating to Feedlot Operations." The published patent contains an unusually complete description of earlier feedlot innovations, patented and otherwise. *See also* Micro Chem., Inc. v. Lextron, Inc., 318 F.3d 1119, 1125–26 (Fed. Cir. 2003) (reversing district court and holding that patentee of feedlot feed mixing system was entitled to lost profits for infringement); Feed Serv. Corp. v. Kent Feeds, Inc., 528 F.3d 756, 758, 764 (7th Cir. 1976) (affirming district court in finding process and composition patent for ethanol and urea liquid feed for feedlot cattle valid but reversing finding of infringement).

118. *See* PERFORMANCE LIVESTOCK ANALYTICS, https://www.performancelivestockanalytics.com/ (last visited July 19, 2020) (promoting cattle feeding software).

119. *Compare Field Robot Market Lacks Direction and Collaboration*, FUTURE FARMING, (Oct. 24, 2019), https://www.futurefarming.com/Machinery/Articles/2019/10/Field-robot-market-lacks-direction-and-collaboration-489136E/ (reporting that high volatility among robot manufacturers deters farmers from wanting their products; that highest demand is for crop harvesting and weed removal robots, to reduce the use of chemicals; but reporting on significance of John Deere purchase of Blue River Technology, which is pioneering weed recognition with AI) *with* Sam Francis, *John Deere Showcases Autonomous Electric Tractor and Other New Tech*, ROBOTICS & AUTOMATION (Nov. 19, 2019), https://roboticsandautomationnews.com/2019/11/19/john-deere-showcases-autonomous-electric-tractor-and-other-new-tech/26774/ (reporting on autonomous tractor with implements for spraying row crops). "Blue River has designed and integrated computer vision and machine learning technology that will enable growers to reduce the use of herbicides by spraying only where weeds are present, optimizing the use of inputs in farming—a key objective of precision agriculture." *Deere to Advance Machine Learning Capabilities in Acquisition of Blue River Technology*, JOHN DEERE (Sep. 6, 2017), https://www.deere.com/en/our-company/news-and-announcements/news-releases/2017/corporate/2017sep06-blue-river-technology/ (press release). *See also* Frank Tobe, *Case IH Displays New Cab-Less Concept Tractor*, ROBOT REP. (Sept. 4, 2016), https://www.therobotreport.com/case-ih-displays-new-cab-less-concept-tractor/ (reporting on demonstration of concept for robot tractor with no buyers yet).

4. *Can Robots Be Made to Do Cowboy Work?*

The state of robot technology is such that some types of robocowboys, such as self-driving cattle trucks ("Texas"), are clearly feasible. Robocowboys that operate in feedlots ("Montana") are likely feasible as well. Whether a robocowboy that operates on the range ("Dakota") is feasible presents harder questions.[120] The following sections apply the foundation of robot technology developed in previous sections of this article to specific cowboy tasks to illustrate the possibilities and problems. Their designers must focus on those tasks and design appropriate components and subsystems for them. The following subsections start with the easiest task, driving a cattle truck, and conclude with the hardest, herding cattle on the range.[121]

a. Texas: a self-driving cattle truck

Robotrucks would be involved in three stages of beef production. One would haul cattle from the range to the feedlot. Another would haul cattle from the feedlot to the slaughterhouse. A third would haul packed beef from the slaughterhouse to wholesale and retail distributors. The first stage requires more specialized capability than the latter two, and the third stage requires the least specialized capability of all. Moving packed beef from a slaughterhouse to a wholesaler or a retailer is no different from moving any other kind of packaged goods from one place to another. It would take place on regular highways between well-equipped freight loading docks.

Self-driving vehicle technology is well developed and functions well on limited-access highways. As of 2019, a Tesla Model Three[122] can navigate an interstate highway and most urban roads reliably and safely, staying in its lane, making lane changes only when prompted by the operator and having determined there is no other vehicle in the way, following a prescribed distance from the vehicle in front of it, starting and stopping with traffic flows. It gets lost, however, when its automatic pilot is triggered on a

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120. It may be helpful to think of a robocowboy as a specialized kind of self-driving vehicle. In that respect Dakota and Montana are related to Texas, in that all three move around in order to do the work of their human counterparts, Kirby, Nash, and Bennington. They differ, however, in the specific tasks that they perform.

121. The specialties are not entirely distinct. Herding, for example, takes place in feedlots as well as on cow-calf ranches. Feedlot herding involves moving smaller herds of cattle shorter distances from one pen to another. *See* Gottsch Livestock Feeders, *Gottsch Livestock Feeders—Feedlots*, YOUTUBE (Sept. 6, 2017), https://www.youtube.com/watch?v=_Knd8O5lZhI (video explaining responsibilities of cowboys and other employees at large feedlot).

122. The author has owned a Tesla Model Three since October 2018 and regularly uses its autopilot function on interstate highways, urban expressways and surface streets.

secondary road without stripes marking the centerline and the sides of the road.[123]

Discriminating between the side of the pavement and an unpaved shoulder is much harder than maintaining a prescribed distance from a white line, and discriminating between the surface of an unpaved road and the shoulder or the drainage ditch is even harder.[124] The point is not that robotics cannot be designed to operate in remote territory; they can. The point is that the design challenges are much greater, and therefore, the technology is much more expensive.

Some other trucking operations associated with cattle production would be easier to automate than others. An example is a feed truck in a feedlot. The feedlot design is well known, as is the location of the receiving and mixing areas for feed and the feed banks where feed is delivered and from which the cattle eat.[125] So a self-driving feed truck presents few challenges in terms of programming it to make the appropriate movements. The difficulties associated with operating on unpredictable routes and on unimproved roads are absent.

On the other hand, picking up and loading cattle from widely dispersed cow-calf operations would require the robotruck to operate on poor roads—off road, in many cases—and to deal with a variety of structures for loading and unloading.[126] These are challenges that automation has trouble dealing with because they are so unpredictable.[127] A major part of the problem is

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123. A 2020 would be classified as a level 3 autonomous vehicle. *See Automated Vehicles for Safety*, NHTSA, https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety (last visited July 20, 2020) (defining levels of automated vehicle from 0 to 5; indicating that the 2020 state-of-the-art is limited to level 3 conditional automation, where driver is a necessity and must be ready to take control at all times with notice; defining level 4 as high automation, where the vehicle performs all functions under certain conditions, but driver may have option to take control, and level 5 as full automation, where the vehicle is capable of performing all functions under all conditions and the driver is essentially a passenger and has no driving responsibility).

124. "[H]ighways tend to be more predictable and orderly, with road surfaces typically well maintained and lanes well-marked. In contrast, residential or urban [and low-density rural] driving environments feature a much higher degree of unpredictability with many generic objects, inconsistent lane markings, and elaborate traffic flow patterns." Quadocular Sensor Design in Autonomous Platforms, U.S._Patent No. 10,192,113 (describing system with multiple cameras and auxiliary sensors for positional awareness for improved machine speed and accuracy).

125. *See generally supra* note 113.

126. The Society of Automotive Engineers' (SAE) J3016 document defines six level of driving automation, only the highest one of which involves autonomous operation in all conditions. *See* Jennifer Shuttleworth, *J3016 Automated-Driving Graphic Update*, SAE INT'L (Jan. 7, 2019), https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic.

127. Machine learning is not the solution for unpredictability that the general press breathlessly claims that it is. Machine learning depends upon presenting a computer system

teaching or otherwise programming the robot to know what to look for in its environment in order to maintain its orientation and to do its job. Where is the edge of the road? Do those light tire tracks and flattened grass mean that the road continues that way? Where is the gate of the corral containing the cattle? Where is the ramp? How does the ramp latch to the bed of my truck trailer?

For these reasons, self-driving trucks may be slower to penetrate the cattle hauling market than other aspects of the trucking industry. Self-driving vehicle technology works better in controlled environments than in uncontrolled and unpredictable ones. Major shipping companies are testing self-driving trucks on long-haul routes on interstate highways.[128] John Deere has an autonomous tractor on the market.[129]

The market for self-driving trucks in any application is determined by a comparison of the cost of buying a robotic truck and the cost of hiring a truck driver to operate a conventional truck. Designing Texas to link cow-calf operations and feedlots and to link most feedlots with processing plants requires him to operate on unimproved roads to facilities that have little advanced technology. He could not be limited to interstate highways and the pathways connecting buildings in high-tech manufacturing facilities. It is likely to remain much cheaper to hire Bennington to drive a conventional truck than to design and build a Texas that will navigate all the routes autonomously.

It will, thus, be some time before self-driving trucks have a material impact on cattle hauling operations, even after they have taken over much of long-haul over-the-road trucking.[130] Bennington probably has a job for as

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with thousands of images or other representations of reality. The more similar the learning examples, the better the learning, and the more reliable the resulting robot program. Trying to use this technique with widely varying robot environments greatly complicates the learning process and at some point renders it all together infeasible as a way of programming a robot. *See supra* Part III.A.3.a–c.

128. *See* Marc Vartabedian, *UPS Invests in Self-Driving Trucks*, WALL ST. J., Aug. 16, 2019, at B5 (reporting on acquisition by UPS of a stake in TuSimple, an enterprise testing over-the-road autonomous class 8 semi-trailer trucks; TuSimple also testing 1000-mile mail haul for the U.S. Postal Service); TUSIMPLE, https://www.tusimple.com/ (last visited July 19, 2020) (website of TuSimple, advertising goal of "depot to depot" autonomous trucking). *See also* KODIAK, kodiak.ai (website for self-driving truck developer) (last visited Aug. 4, 2020).

129. *See* Sebastian Blanco, *CES 2019: John Deere Highlights Tractors' Autonomy*, TRUCKS (Jan. 10, 2019), https://www.trucks.com/2019/01/10/ces-2019-john-deere-autonomous-tractors-precision-agriculture/ (describing John Deere "autonomous tractor" shown off at the 2019 consumer electronics show; equipped with cameras and GPS sensors, it can plow rows with accuracy of less than one inch, but requires live attendant to steer it around obstacles).

130. *See* Jon Walker, *Self-Driving Trucks—Timelines and Developments*, EMERJ (last updated Feb. 2, 2019) https://emerj.com/ai-adoption-timelines/self-driving-trucks-timelines/ (reporting on plans by specific manufacturers for self-driving trucks with and without moni-

long as he wants it. When Texas gets hired to replace him, a full array of regulations will be in place for self-driving trucks, as Part III.B.5, *infra*, explains. Nothing new will be required for Texas.

b. Montana: a robocowboy for feedlots

In addition to herding robots, cow-calf operations and feedlots need feed delivery robots. The design of Montana for feedlot applications is simpler than the design of Dakota for open range operations, because the locations of the cattle, feed sources, feed bunks[131] for delivery of feed, and guideways connecting them are fixed and known in advance.[132] The feed delivery robot must have a system for recognizing markers defining each of these places. The markers can be visual stripes of a design distinguishing sources of feed, guideways, and different feed bunks, or they can be radio-frequency-emitting devices. The feed delivery robot must have sensors appropriate for recognizing these markers. Each machine also needs appropriate sensors for measuring the quantity of feed aboard.

Montana's basic algorithm causes him to visit the feed source, connect himself to it, and receive a sufficient quantity of feed to fill himself up. Once Montana is full, his algorithm commands him to disconnect and to follow the appropriate guideway leading to the destination feed bunk for that particular load of feed. When Montana's sensors detect arrival at the destination feed bunk, his algorithm causes him to stop, to deploy his delivery chutes, and to deliver the requisite quantity of feed to that feed bunk. If Montana is to deliver to another feed bunk on that same trip, the algorithm

tors onboard; providing statistics on labor costs of conventional technology and numbers of truck driver jobs).

131. A feed bunk is an extended trough made out of concrete or metal into which pre-mixed feed is poured and from which cattle eat by sticking their heads through spaces in a specially constructed fence at the boundary of a pen abutting the feed bank. *See Feed Bunk*, WIESER CONCRETE, https://wieserconcrete.com/product/feed-bunk/ (last visited July 9, 2020) (advertising pre-cast concrete feed bunks); *Behlen 10 Ft. Feed Bunk*, HOME DEPOT, https://www.homedepot.com/p/Behlen-10-ft-Feed-Bunk-22121798/100319442 (last visited July 9, 2020) (offering galvanized steel feed bunk). *See also* Erin Laborie, *Profit Tip: Consistency Is Key to Property Feed Bunk Management*, DROVERS (Aug. 28, 2017, 7:40 AM), https://www.drovers.com/article/profit-tip-consistency-key-proper-feed-bunk-management (including photograph of cattle feeding at a feed bunk).

132. *See generally* Baxter Black, *Feedlot Cowboy*, TRI-STATE NEIGHBOR (June 23, 2018) https://www.agupdate.com/tristateneighbor/opinion/columnists/baxter/feedlot-cowboy/article_92235332-69a3-11e8-85c5-e3d8b7ac1ed7.html (describing activities of cowboys on feedlots); *Ranch Jobs: Wanted—Feedlot Cowboys*, RANCHWORLDADS (Sept. 13, 2018), http://www.ranchworldads.com/classified.php?listing=95953 (giving job description for feedlot cowboy); Kansas Beef, *Pen Riders—The Feedlot Cowboys*, YOUTUBE (June 12, 2018), https://www.youtube.com/watch?v=yxaLh0KRn60 (describing and showing activities of feedlot cowboys).

would cause him to visit each feed bunk in sequence. When he needs more feed, the algorithm would cause Montana to return to the source.

Neither the sensors nor the algorithms required for this level of functionality are particularly sophisticated. The targets for Montana's movements are not themselves going to be in motion, and the actions Montana must take at each place are simple. They require little more than stop and start commands for loading, delivery, and movements, with simple steering required to follow the guideways. The mixing of the feed in the correct proportion for animals of different weights, maturity, and health conditions is already mostly automated at bigger feedlots.[133] So Montana's designers need not reinvent these technologies; they need only to interface with them.

Some versions of Montana may be stationary robots. They could handle most of the feeding operations in feedlots if they were integrated with other automated cattle feeding systems.

Because Montana operates in feedlots—a confined environment—his operations are much like those of a factory robot, already regulated by OSHA, as Part IV.C, *infra*, explains.

c. Dakota: a robocowboy for the range

Dakota is the king of the robocowboys because he must handle the most difficult job. Other aspects of robotics will replace much of what Kirby does. Inexpensive drones will observe herds, pinpoint their locations for roundups, and identify sick or injured cattle.[134] They will enable a smaller number of cowboys like Kirby to be dispatched to deal with problems exactly where they occur. Wheeled robots will drive cattle.[135] Operating in conjunction with automatically operated and synchronized gates, these robots will move cattle from one corral to another and load them off and on truck trailers.

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133. *See 5 Ways to Improve Feedlot Efficiency Through Automation*, AUTOMATED PROCESS EQUIPMENT CORP. (Mar. 5, 2019), https://www.apecusa.com/blog/5-ways-to-improve-feedlot-efficiency-through-automation/; Regis Boily, *Digital Control for Automating Feed Distribution in Feedlots* (1980) (unpublished Ph.D. dissertation, Iowa State University) (on file with the Iowa State University Digital Commons), https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=7685&context=rtd.

134. *The Practicality of Drone Use in Ranching*, DROVERS (Sept. 13, 2016, 9:07 AM) https://www.drovers.com/article/practicality-drone-use-ranching (concluding that inexpensive drones can be useful for herding, monitoring fences, and finding lost stock); Heather Smith Thomas, *Are You Ready for a Drone?*, CANADIAN CATTLEMEN (Nov. 28, 2017), https://www.canadiancattlemen.ca/2017/11/28/should-you-get-a-drone-for-your-cattle-operation/ (describing inexpensive drone use on cattle ranches).

135. *See Meet the Robot That's Making Cattle Herding Safer*, CARGILL (Oct. 18, 2018), https://www.cargill.com/story/meet-the-cowboy-robot-thats-making-cattle-herding-safer.

But how much of Kirby's remaining job will be replaced by Dakota depends on how much Dakota costs. Kirby has lots of specialized skills, integrated in ways that are subtle and difficult to articulate and define. And Kirby comes pretty cheap. Designing and building Dakota to do what Kirby does is very expensive, and it is not clear that Dakota would be able to do his job as well or as quickly as Kirby does it. So the mere possibility of advanced robot technology does not necessarily mean a lost job opportunity for Kirby.

The following sections describe in detail the technology that Dakota needs, to give a more tangible appreciation of the costs likely to be involved in developing it.

i. Functions performed

Understanding the potential for robotics on the cattle range (broadly defined) benefits from a careful classification of the functions performed by human cowboys, breaking down tasks into more specific acts of perception and motion that comprise those tasks. The process is one familiar to industrial engineers, who often conduct time and motion studies as a means of understanding how to improve worker productivity and how to automate certain assembly line tasks. In AI parlance, this is "knowledge engineering."[136]

Best understood by the general public—by anyone who has ever watched a western movie—one function involves herding cattle, moving them from one place to another. In the nineteenth century, this was done largely on horseback; at the end of the twentieth century and the beginning of the twenty-first, it was done on foot and in a variety of vehicles such as ATVs and jeeps, and occasionally on horseback.[137]

In the nineteenth century, herding occurred over short, medium, and long distances. The cattle drive was the longest, spanning 600 miles from the hill country of Texas to Dodge City, Kansas, or 950 miles from the hill country to Cheyenne, Wyoming.[138] Roundups represented medium-distance herding. In the nineteenth century, they involved collecting cattle from widely dispersed points on the open range and putting them into enclosed

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136. *See* Larry Lafferty, *What You Should Know About Knowledge Engineering*, FORBES (Jan. 8, 2019, 7:45 AM), https://www.forbes.com/sites/forbestechcouncil/2019/01/08/what-you-should-know-about-knowledge-engineering/#44c879155a47 (explaining knowledge engineering).

137. *But see* Tim Farmer, *Herding and Roping Cattle the Old Fashioned Cowboy Way*, YOUTUBE (Oct. 8, 2016), https://www.youtube.com/watch?v=RyLmR1DVJKI (arguing that cowboys on horseback are superior to cowboys on motorized vehicles; showing techniques for grounding cattle).

138. *See* Perritt, *Rise and Fall*, *supra* note 1, at 376–78.

areas from which they could be organized for a long drive. Now, when range ranching is far less common, and the roundups mostly comprise collecting cattle from enclosed pastures of a few hundred acres, short-distance herding involves a combination of sorting cattle, counting them, and moving them into smaller corrals for sale to customers who want particular types and weight. Eight to ten cowboys typically are involved in driving a herd of any significant size.[139] Cowboys spread out the back of the herd and move their horses to induce individual cattle to close the distance between them and the rest of the herd and to keep the herd moving in the desired direction.

This activity comprises several distinct perceptual tasks and physical movements. Each cowboy must track the positions of the other cowboys. To do this, he must recognize each as a cowboy and record and update their positions at intervals of a few seconds. He must also see where the herd is and track its position and direction of movement. This requires identifying groups of cattle and assigning a density to them. Third, he must detect individual cattle separated from the herd, noting their position and direction of movement, calculate their distance from the herd, and calculate what must be done to their position to cause them to merge into the herd.[140] The cowboy then must identify the drifters to which he is closest, compared to the other cowboys. There might or might not be some negotiation between cowboys as to which one of them will handle a particular drifter or straggler.

Then the cowboy positions his horse to approach the drifter from behind, defined in terms of the direction he wants to move the drifter. He arrests his movement when he is a prescribed distance from the drifter, usually six yards or so, maintaining that distance and adjusting his lateral position to cause the cow to move in the direction of the herd. To do this, he needs to understand the basics of bovine psychology, such as their herd instinct, which causes them to desire to be part of the herd rather than being separated from it, and their fear of any animal other than a beef, manifested by their tendency to move away from it. Those tendencies give rise to the basic act of herding: approaching the animal to be herded from behind and moving

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139. Although one driver claims he can move a group of cows with two Border collies. *See* Jaime Lowe, *How to Drive Cattle*, N.Y. TIMES MAG. (Jan 6, 2017), https://www.nytimes.com/2017/01/06/magazine/how-to-drive-cattle.html. *See* CHRISTOPHER KNOWLTON, CATTLE KINGDOM: THE HIDDEN HISTORY OF THE COWBOY WEST 19–20 (2017) (describing positioning of cowboys to drive a herd); Perritt, *Rise and Fall*, *supra* note 1, at 378–80 (reporting about fifteen cowboys per herd and 1500-mile trek to railhead). The direct distance from the Texas Hill County to Dodge City was 600 miles, but cattle herds had to circumnavigate streams and other obstacles and also went to more distant railheads.

140. For convenience in exposition, this article refers to cattle separated from the main herd as "drifters."

slowly to close the distance between the herder and the animal, causing the animal to move to stay away from the herder.[141]

Once the herd is started, point riders ride alongside or just behind the lead steers, keeping them going in the right direction. Swing riders position themselves on either side of the herd, about a third of the way back. Flank riders, similarly, ride on each side about two-thirds of the way back. Swing and flank riders keep the herd bunched up and chase down strays and force them to return to the herd. Drag riders ride behind the herd and are responsible for forcing laggards to keep up with the rest of the herd.[142]

A second activity is locating stragglers. Individual cattle sometimes stray from the main herd and wander off by themselves because they are infirm or because they are searching for water or better feeding areas. Unless they are to be sacrificed and their numbers chalked up to losses, a rancher must find them and return them to the main herds. In the nineteenth century open range, this activity involved a cowboy on horseback "riding the range," using his knowledge of the terrain to look for likely hiding places.

As the size of ranges and pastures has shrunk throughout the twentieth century, and as enclosed pasturage has become the norm rather than the exception, searching for strays has become less demanding; strays cannot wander as far away as they used to, and their hiding places are more limited.

In all of their activities involving contact with cattle, cowboys must be observant, looking for signs of illness or injury, determining the readiness of particular cattle for the next stage in production, and assessing their fitness for additions to the herd as breeding stock. When this activity is done by a human cowboy, it involves a high level of skill, applied holistically, and backed up by a substantial amount of experience. A first-time visitor to a cattle ranch would be of little use in performing this function; an experienced rancher performs it instinctively, probably without being able to articulate exactly what he is looking for.

Cowboys frequently must cut a specific animal from the herd, separating it so that it can become part of another herd or so that it can receive some sort of individual attention.[143] Cutting requires the performance of

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141. *See* KNOWLTON, *supra* note 139, at 19–20 (describing positioning of cowboys to drive a herd). *See generally* Whit Hibbard & Dawn Hnatow, *How to Properly Gather Cattle, and How Not To*, DROVERS (May 11, 2018, 2:14 PM), https://www.drovers.com/article/how-properly-gather-cattle-and-how-not (providing tips on how to move cattle effectively and gently); Whit Hibbard, *Start Herd Movement the Right Way*, DROVERS (Dec. 12, 2016, 8:22 AM), https://www.drovers.com/article/start-herd-movement-right-way (offering guidance for the biggest problem—starting first-calf heifers and young calves).

142. *See* KNOWLTON, *supra* note 139, at 19–20 (describing positioning of cowboys to drive a herd); Lowe, *supra* note 139.

143. *See supra* notes 27–32 and accompanying text.

several acts. First, the target beef must be identified. Second, the cowboy must position himself, probably mounted on the horse or a wheeled vehicle, between the target animal and the rest of the herd. Third, the cowboy must use a combination of noise and movements to nudge the herd and the target animal away from each other. Finally, the cowboy must drive the target animal to a pen where it can be confined, perhaps with other animals that have already been cut from the herd.[144]

Everyone has seen cowboy movies in which a cowboy lassos the steer, uses his horse to apply tension on the rope, and pulls a steer to the ground, dismounting and tying the steer's legs preparatory to branding it. Branding has gone rather out of fashion in cattle operations. Cattle are now marked with ear tags or other tags affixed to other parts of their anatomy, and increasingly digital chips are planted under their skins.[145]

It is still necessary, however, to immobilize individual beeves to evaluate them, treat them, identify them, or weigh them. One straightforward way to do this is to enclose the animal in a small pen.

Most twentieth and twenty-first century cow-calf operations employ supplemental feed, beyond grass on the pasture.[146] In such operations, cowboys must load sacks of feed or bales of hay and distribute them to the cattle. In pastures, this is done by tractor, spreading out a line of hay near the herd.[147] In feedlots, it is done by delivering quantities of feed designed for particular groups of cattle to feed banks in the enclosures containing the cattle.[148]

On a range, cattle move about, seeking more desirable grass as they graze. A cowboy delivering supplementary feed, as would be the case in the

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144. *See supra* notes 27–32 and accompanying text.

145. *See* Ted Genoways, *Why Cattle Branding Is Still a Thing* (Sept. 19, 2017, 1:00 AM), https://www.thedailybeast.com/why-cattle-branding-is-still-a-thing (summarizing criticisms of hot branding and describing substitute identification methods).

146. *See It's Time to Put a Pencil to Your Feeding Program*, BEEF MAGAZINE (Apr. 26, 2018), https://www.beefmagazine.com/nutrition/it-s-time-put-pencil-your-feeding-program (describing feed supplementation for cow-calf operations).

147. *See* Wendy Sweeter, *Are Range Cubes an Option for Your Operation?*, PROGRESSIVE CATTLE (June 9, 2015), https://www.progressivecattle.com/topics/feed-nutrition/are-range-cubes-an-option-for-your-operation (describing options for delivering feed to range).

148. *See* John W. Comerford et al., *Feeding Beef Cattle*, PENNSTATE EXTENSION (Jan. 29, 2014), https://extension.psu.edu/feeding-beef-cattle (describing use of feed bunks in feedlots).

wintertime for northern ranges,[149] cannot know in advance where the herd is or how to get from the feed supply to that place.[150]

Once the cowboy reaches the herd, he must have an appropriate unloading and delivery mechanism to lay a string of feed along the ground. This mechanism must be able to handle hay and other forage as well as grain.[151] Supplementary feeding on the range rarely involves only grain.

On cattle ranches that grow their own feed, cowboys are responsible for mowing and baling hay and moving it to storage areas and may be responsible for harvesting corn and moving it to silos for storage. When corn is cultivated on farms not also raising beef cattle, these functions are performed by farm workers not denominated as cowboys.

Most cattle are raised with only infrequent intervention by licensed veterinarians. Large animal veterinarians teach cowboys how to perform basic and simple functions for dealing with cattle in distress. For example, cowboys routinely give injections with hypodermic needles and syringes, administer other medicines by mouth, dress minor wounds, and provide assistance to mothers having difficulty delivering calves.[152]

ii. Automating herding

This article develops the concept of Dakota more fully than the concept of Montana or Texas. Robotic semi-trailer truck tractors are already highly developed. Feedlot robots will function more like industrial robots, which also are more highly developed. The designer of a Montana or a Texas robot will likely adapt hardware and software that already exist in those applica-

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149. *See* Jesse Bussard, *Bale Grazing Gets Them Through Winter*, HAY & FORAGE GROWER (Feb. 21, 2019, 10:53 AM) https://hayandforage.com/article-2367-Bale-grazing-gets-them-through-winter.html (describing one cow-calf operator's method for winter feeding with pre-placed bales).

150. *See generally Precision Ag Technology*, JOHN DEERE, https://www.deere.com/en/technology-products/precision-ag-technology/#do-more (last visited July 7, 2020) (describing products for agriculture equipment data management, remote management, guidance of mobile equipment, and variable rate application).

151. *See, e.g.*, *BU10 Series Bale Unroller*, JOHN DEERE, https://www.deere.com/en/hay-forage/handling/bu10-3-point-bale-unroller/ (last visited July 7, 2020) (device for unrolling bales of hay for feeding; designed to be pulled by tractor or other towing vehicle).

152. *See* Bo Brock, *Vet Recounts a Cowboy's Surprise*, DVM 360 (June 30, 2012), https://www.dvm360.com/view/vet-recounts-cowboys-surprise (describing interaction of veterinarian and cowboys); *see also* Ariel Ramchandani, *The 21st-Century Cowboy*, ECONOMIST (July 24, 2014), https://www.economist.com/1843/2014/07/24/the-21st-century-cowboy (describing activities of modern cowboy); CalifBeefCouncil, *21st Century Cowboys*, YOUTUBE, https://www.youtube.com/watch?v=e65PjyBJlQ4 (last visited Aug. 23, 2020) (describing activities of modern cowboys, including use of dogs to find cattle); Wikipedia, *Modern Working Cowboys*, https://en.wikipedia.org/wiki/Cowboy#Modern_working_cowboys (last visited 23 Aug. 23, 2020) (describing functions and activities).

tion spaces. The idea for Dakota, however, requires a more comprehensive design from the bottom up. Because of the novelty of the concept, the article provides more details about the design task to see what is likely to be required to build a satisfactory Dakota.

(a) What a robot cowboy must do

Dakota must be able to perform herding tasks described in Part III.A.2.c.i.[153] A robotic cowboy must be able to replicate these tasks. It must be able to recognize cattle and distinguish them from cowboys. It must be able to represent the position of each cowboy and track his position as it changes, with a frequency proportional to the maximum rate of change. It must be able to discriminate between an animal that is part of the herd and one that is a straggler, based on the distance between each animal and substantial groups of animals. It must be able to calculate the distance between it and each other cowboy, between it and the animals constituting drifters and those defining the edges of the herd. It must be able to calculate the distance between each other cowboy and drifters in the herd.

It must "know"—have an algorithm that represents—how to herd a straggler to close it up with the rest of the herd by approaching it, maintaining the requisite distance, and continuing to move to cause the drifter to walk toward the herd.

When one looks at a video recording of a cowboy on horseback herding a recalcitrant beef, one cannot help but be impressed by the agility required of the horse and cowboy combination. The horse must accelerate quickly to exceed the pace of a calf who has suddenly broken into a run, stop immediately, and turn in various directions to maintain its position with respect to the cow's flight zone and point of balance, and the cowboy must control these movements quickly and with a fine touch. Programming this agility into a robot presents the greatest challenge of robocowboy robotics.

Two approaches are available to teach Dakota how to herd cattle. The first requires less of the technology, while the second presses close to the frontier of the current state-of-the-art. The first, less ambitious, approach uses machine learning to teach Dakota only how to recognize cattle. That can be done with still images. He acquires knowledge about how to herd them by being programmed with traditional, rule-based algorithms. The

153. The section concentrates on the herding function. Other functions, such as feeding, tagging, or administering medicine require distinct analysis, but are, on the whole, simpler than herding. A feeding robot, for example, needs search-and-find capabilities similar to a herding robot, and it must have a propulsion system and drive appropriate for navigating unpredictable terrain on the way to the herd's location, just like the herding robot. It does not need the capability of identifying stragglers and moving them back into the herd, however.

second, more ambitious approach uses machine learning to teach Dakota to recognize cattle and how to herd them.

One of the theses of this article is that a cattle-herding robot is possible, but it is certainly not possible to set forth the complete specifications for such a robot in a law review article. Instead, this section describes how machine learning could teach Dakota how to recognize cattle and gives examples of rule-based algorithms that tell him how to herd them. Those algorithms permit him to detect strays from the herd, to close in on them, and to drive them back to the herd. Similar algorithms enable him to drive the entire herd in a desired direction.

(b) Integrating sensors and servomechanisms

The hard part of designing Dakota, a robocowboy for herding, involves the algorithms; hardware is less of a challenge. Engineers can design parts of a machine that perform useful tasks in much the same way that human beings perform them. They can build drive systems, usually comprising wheels for land vehicles, each driven by an electric motor. Sensors attached to the axles determine rotational speed, and the control algorithm adjusts the voltage and frequency applied to the motor to maintain a commanded speed. A higher-level algorithm determines speed differentials among a multiplicity of wheels to turn the vehicle at a prescribed rate of turn. A sensor designed to detect the angle of rotation and its rate of change for the vehicle as a whole can support a feedback loop to ensure the prescribed rate of turn, even if some of the wheels are slipping.[154]

Dakota will look like a Gator, a brand of UTV,[155] except that Dakota will not have seats, a windshield, or an enclosed cab.[156]

A combination of cameras, radar, and LiDAR sensors can support vehicle perception of other cowboys and the beeves, while control logic enters the positions determined by them into an internal database and constantly updates it as new signals are obtained from the sensors.

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154. The author knows this as a result of his education as an aeronautical engineer and his training as a helicopter and instrument airplane pilot.

155. *Full-Size Gator™ XUV Crossover Utility Vehicles*, JOHN DEERE, https://www.deere.com/en/gator-utility-vehicles/full-size-crossover-gators/?CID=SEM_Res_enUS_Dcom_XUVCID=SEM_Res_enUS_Dcom_XUV&source=GOOGLE&medium=cpc&account=xuv&campaign=Generic+-+Utility+Vehicles_Phrase&adgroup=ATV&keyword=atvs&gclid=Cj0KCQiAkKnyBRDwARIsALtxe7jhmM49B9CxwNzTHVbYUY_Ma-4NUOaUbVjUoWf4M7Aa1Ls76ZCWiKgaAiAoEALw_wcB (last visited July 7, 2020).

156. It is possible that Dakota might be a drone. The distance involved in a particular herding activity has an impact on the potential for automation. If a robocowboy must be able to travel substantial distances quickly, being airborne might be an advantage. Operating continuously for a long time, however, would favor ground vehicles.

GPS sensors allow the robot to calculate its absolute position in space, thus reinforcing relative position calculations derived from direct measurements. The GPS-determined data also can be transmitted via a radio link to a central control station for the ranch, informing it of the position of the herd and the cowboys herding it.

Higher-level control logic, embedded in algorithms, decides which animal the robot should choose as a target and then commands the necessary movements to cause it to approach the target and drive it toward the herd.

(c) Algorithms for herding[157]

The set of algorithms that enable a robocowboy to force a stray back into the herd are the same ones that would be used to position a team of robocowboys to drive a herd to a particular place. Each robot must determine that its target is not doing what is desired, it must move to intersect its target, and when it is close, within the flight zone, it must adjust its movement to cause the target to move in a particular way. Each of those stages of cattle driving is necessary for herding a single stray. Each also is necessary for driving an entire herd. The following sections describe the technologies needed to perform the essential functions of a robocowboy.[158] The appendix contains Python computer code that illustrates how herding algorithms would work. The code is realistic, and the author has debugged it in the programming environment Thonny, but it is much simplified, compared to what actually would be necessary for a functioning robocowboy. The appendix shows the Python code[159] that performs these steps:

1. If an animal has separated from the herd,

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157. The algorithms assume that Dakota has some way of localizing the herd and potential strays from it. That can be done either because each animal has an RFID device that broadcasts its location or because Dakota himself has sensors capable of seeing and fixing the location of each animal.

158. Analysis of the requisite algorithms could be accomplished from the perspective only of the robot, in which case everything should be seen through its eyes, or from the perspective of an observer of range cattle operations. The former—robot—perspective is more useful because the robot is going to work as a cowboy, not as a stray or a herd.

159. The author initially developed the code in Swift, and then translated it into Python. The Swift programming language was developed by Apple for writing iPhone apps. It is newer than Python, represents a hybrid of Python and C++ concepts, and is compiled rather than being interpreted (which makes it faster at runtime). Python is a popular programming language that increasingly is being used by machine learning programmers. Python libraries exist that considerably facilitate use of training sets of images in the construction of image recognition algorithms. Python is not strongly typed, which makes it much easier for nonexpert programmers to use. It is, however, interpreted instead of being compiled, which makes it slower. Its potential speed, however, can be evaluated as part of the robot system design process to see if it is fast enough to meet the needs of a particular application.

2. Position myself on an extension of the vector from the animal to the herd,

3. So that I am inside the animal's flight zone;

4. As the vector from the animal to the herd changes, maintain myself on the extension of that vector,

5. Inside the flight zone;

6. Move outside flight zone when the distance from the animal to the herd is less than the herd-interval distance.

As noted above, for all positions of herd, target, and robot, the calculations for intercept point, and intercept vector must be constantly updated as new data is received on positions. The appendix shows the overarching loop for this updating.

Supporting algorithms model straggler behavior when a robot gets within its flight zone, model herd behavior, and compute headings and distances between the participants in the herding.

These algorithms would work satisfactorily as long as there were no physical obstacles between the animal and the herd and the robot and the animal. If a tree, heavy growth of brush, or a gully intervenes, the robot must have an additional capability of calculating the best way to circumvent the obstacle while remaining as close as possible to the herding vector and to resume its position on the herding vector as soon as it is clears the obstacle.

Perception sensors and their supervising subsystems can periodically output the x and y positions of any object they are programmed to recognize. The herding system must update the positions of herd, animal, and robot frequently. Every 0.10 second should be adequate to accommodate quick movements.[160] The computations necessary to update positions from sensor readings and for translating movement commands from the algorithm into commands to wheel motors must not take longer than the position-update increment.[161]

The logic involved in the algorithms is not unlike the logic involved in algorithms for drones[162] and manned aircraft navigation traffic separation

160. If one assumes that a quick-moving cow moves at twenty miles per hour, the cow would move about three feet in 0.10 seconds.

161. It would not be useful to write code that would simply compute the positions of herd, stray, and robot and express their spatial relationships with each other statically; the whole idea of herding cattle involves movement. This means that a useful program must iterate with respect to time, using relatively small-time increments, because of the rapidity with which one or another of the three objects changes its position or direction of movement. To achieve that, the entire cowboy robot program runs in a loop, as illustrated in the first part of the Appendix.

162. *See generally* Henry H. Perritt, Jr., & Albert J. Plawinski, *Using the Internet to Make Drones Safe*, 19 J. INTERNET L. 1, 17–21 (2015); Henry H. Perritt & Albert J. Plawinski, *Making Civilian Drones Safe: Performance Standards, Self-Certification, and Post-Sale Data*

and for inertial guidance systems for intercontinental ballistic missiles, which the author worked on when he was an engineering student at MIT.

Once an animal detects that a herder has moved into his flight zone, it begins to move away on the same heading as the approaching herder, at the animal's flight speed, which in the real world increases in proportion to how far its flight zone has been invaded.

The robocowboy has an alert function that tells it when a beef has strayed from the herd and become a straggler. The alert function in the Appendix returns the value "True" when the target animal has separated from the herd and "False" when it is still in the herd. Parameters for the function are the latitude and longitude of the herd and of the potential straggler.

The algorithms comprising the herding program may allow for the possibility that more than one robocowboy is on the range tending to a particular herd. When that is the case, the robocowboys must be able to communicate with each other and decide who will handle any alerts. The algorithm for making this decision is straightforward: whoever is closer to the stray will go into action. To enable this, each robot should broadcast its position to the other robots. This broadcasting can be represented by having each robot return the value of a position variable each time an update occurs.

The chaseAStraggler function, illustrated in the Appendix at Figure 2, is activated only when the value of the alert function is "True." Then the chaseAStraggler function takes the position of the stray and the position of the robot and, using basic trigonometry, computes a vector that when followed causes the robot to close on the stray. This method returns a heading value and a distance value that then would be input as parameters to the navigation and propulsion method. The basic calculation for the chaseAStraggler algorithm is to subtract the robot's latitude from the stray's and to do the same thing with their longitudes. The combination of the differences defines a vector, which then is decomposed into heading and distance.

Flight behavior is programmed by causing the straggler to move away from the robocowboy on the heading to the straggler. This approximates the point-of-balance idea from real life flight behavior.[163]

But the chaseAStraggler function needs more, lest it cause the robot to approach the straggler and continue moving so that it collides with it. It needs to recognize when it has reached the boundary of the straggler's flight zone. When that happens, it should adjust its movement to place itself just inside the flight zone at an angle to the stray's alignment that will cause the stray to move back into the herd. The code in the Appendix illustrates that robot behavior.

Collection, 14 NW. J. TECH. & INTELL. PROP. 1 (2016) (both detailing functionality of drone communications, control, and navigation systems).

163. *See* Part III.A.1 (describing cattle flight behavior).

IV. HOW WILL THE LAW SHAPE THE ROLE OF ROBOTS ON THE RANGE?

A. The Past

Two earlier articles in this sequence have explored law's role in defining the cowboy. The *Rise and Fall of the Cowboy*[164] considers how law facilitated the long cattle drives of the nineteenth century and then helped bring them to an end, reinforcing crucial technologies. *Twentieth Century Cowboy* describes how exemptions from transportation regulation and from collective bargaining allowed the twentieth-century industry to decentralize and bifurcate the functions of cattle ranching as an adaptation to truck transportation, subsidies of public highways, and land scarcity.

B. Regulating Robots

At a high level of abstraction, mechanical engineers and computer scientists refer to "Asimov's Laws of Robotics":

> First Law: A robot may not injure a human being or, through inaction, allow a human being to come to harm.
>
> Second Law: A robot must obey orders given it by human beings, except when such orders conflict with the First Law.
>
> Third Law: A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.[165]

Most current proposals for regulation of robots morph into proposals for regulation of AI. Then, the proposals are vague, talking about "build[ing] AI systems that can interact with human norms, rules, and law,"

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164. Perritt, *Rise and Fall*, *supra* note 1.

165. Kseniya Charova et al., *Regulation*, COMPUTERS AND ROBOTS: DECISION-MAKERS IN AN AUTOMATED WORLD, https://cs.stanford.edu/people/eroberts/cs201/projects/2010-11/ComputersMakingDecisions/regulation/index.html (last updated Spring 2011) (quoting Asimov's Laws). Isaac Asimov was, of course, a science fiction and popular science writer and not a lawyer or engineer. But his philosophical concepts have been adopted for the real world of robotics. Jack Balkin emphasizes that practical regulation of robots must impose duties on the people who design and use them, not on the robots themselves. *See* Jack M. Balkin, *The Three Laws of Robotics in the Age of Big Data*, 78 OHIO ST. L.J. 1217, 1219, 1221–22 (2017). Balkin adapts Asimov's "laws" to reality of AI, machine learning, and robots:
"First law: Algorithmic operators are information fiduciaries with respect to their clients and end-users;
"Second Law: Algorithmic operators have duties toward the general public; [and]
"Third Law: Algorithmic operators have a public duty not to engage in algorithmic nuisance." *Id.* at 1227, 1231–33.

and "build[ing] 'a novel regulatory structure—third-party regulatory markets—to spur the development.'"[166] There is nothing here about the content of regulation or how it relates to specific risks.[167] One 2017 assessment noted that the United States and Europe are more likely to regulate to protect worker safety, while China is more likely to regulate to provide advantages to robots originating in China.[168]

The literature sometimes proposes a new federal agency to regulate robots.[169] For example, University of Washington law professor Ryan Calo has proposed the creation of a Federal Robotics Commission.[170] His proposed commission would not "regulate" in the traditional sense, but it would advise public policy makers at all levels of government on robots, especially those that have the potential to cause physical harm.[171] He draws his examples primarily from automated features of driverless cars, drones, high-speed trading on securities exchanges, cognitive radio, and surgical robots.[172] Calo frames the responsibilities of his proposed commission, however, mostly to encourage the development and deployment of robot technology.[173] Calo stops short of proposing any particular regulatory approach or requirements, although he notes that much eventual robot regulation will be accomplished—or enforced—through code rather than through traditional rules and agency adjudication.[174]

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166. *See* Paula Klein, *Rules for Robots: The Path to Effective AI Regulation*, MIT DIGITAL: BLOG (June 12, 2019), http://ide.mit.edu/news-blog/blog/rules-robots-path-effective-ai-regulation (summarizing presentation by University of Toronto professor Gilllian Hadfield). *See generally* GILLIAN K. HADFIELD, RULES FOR A FLAT WORLD (2017).

167. *See* Andrea Bertolini, *RoboLaw: Why and How to Regulate Robotics*, ROBOHUB (Oct. 29, 2014), https://robohub.org/robolaw-why-and-how-to-regulate-robotics/ (describing European study on the philosophy of regulating robots; suggesting a case-by-case approach to particular applications).

168. *See* Abishur Prakash, *Why Robot Law Around Industrial Automation Varies Worldwide*, ROBOTICS BUS. REV. (Jan. 1, 2017), https://www.roboticsbusinessreview.com/manufacturing/why_robot_law_around_industrial_automation_varies_worldwide/ (thoughtful discussion of different national approaches, some emphasizing worker safety, as in the United States and European Union, and some emphasizing national origin of robots, as in China).

169. *But see* Bertolini, *supra* note 167 (arguing that robots already are regulated, by tort law if nothing else, and that the only legitimate question is *how* they should be regulated).

170. RYAN CALO, BROOKINGS, THE CASE FOR A FEDERAL ROBOTICS COMMISSION 3 (2014), https://www.brookings.edu/wp-content/uploads/2014/09/RoboticsCommissionR2_Calo.pdf [hereinafter CALO, CASE FOR COMMISSION] (proposing federal "agency dedicated to the responsible integration of robotics technologies into American society"); *see also* Ryan Calo, *Robotics and the Lessons of Cyberlaw*, 103 CAL. L. REV. 513, 555–58 (2015) [hereinafter Calo, *Robotics*].

171. CALO, CASE FOR COMMISSION, *supra* note 170, at 3.

172. *Id.* at 6–10.

173. *Id.* at 11–12.

174. Calo, *Robotics*, *supra* note 170, at 559.

He erroneously uses the 1927 Federal Radio Commission as a precedent. That commission, he says, responded to the "need to manage the impact of radio on society."[175] It did not. The Federal Radio Commission responded to a much narrower problem: the need to avoid radio interference between stations operating on the same frequencies.[176] No one has suggested a similarly crisp problem treated by robots, amounting to a need for government intervention, and it is not clear that the public would support such a step.[177]

A far more aggressive approach would prohibit the use of certain types of algorithms until a federal agency determines that they are "safe and effective" and could be controlled to prevent their misuse.[178] Andrew Tutt proposes that the agency itself determine which algorithms are so "opaque, complex, and dangerous" as to be subject to "regulatory scrutiny."[179] He gives examples of possible performance standards, requiring self-driving cars to be involved in fewer than a specified number of accidents per vehicle mile, requiring stock trading algorithms to predict and report volatility of returns on investment, and requiring job applicant screening algorithms not to underrepresent any protected class by more than twenty percent.[180] Tutt's basic approach is so broad that it is hard to understand how far it would reach. Would it, for example, prohibit doing tutorials for PyTorch, available from pytorch.org/tutorials?

Some proposals, superficially reasonable, would have the effect of prohibiting use of the new technologies. Two Berkley law professors, for example, have proposed a system for public participation in the design of machine learning systems used by government agencies.[181] They point to the 1978 EEOC Employment Selection Procedures (Uniform Guidelines) as a

175. *Id.* at 556.

176. *See* FED. COMMC'NS COMM'N, A SHORT HISTORY OF RADIO 4 (2003–2004), http://transition.fcc.gov/omd/history/radio/documents/short_history.pdf (providing timeline of radio history and listing 1927 as the year "[t]he Federal Radio Commission [was] established to bring order to chaotic airwaves); *see also Radio Chaos to End Tomorrow Night*, EVENING STAR, Apr. 22, 1927, at 2, https://chroniclingamerica.loc.gov/lccn/sn83045462/1927-04-22/ed-1/seq-2/ (describing the problem of "wave jumping" and Commission efforts to clear the "chaos" by assigning frequencies).

177. *See* Ashleigh Garrison, *What Americans Think About Creating a New Federal Agency to Oversee the Robots*, CNBC (June 30, 2018, 11:00 AM) https://www.cnbc.com/2018/06/29/what-americans-think-about-a-new-federal-agency-to-oversee-robots.html (reporting results of a poll showing sixty-one percent of respondents are "very uncomfortable or somewhat uncomfortable" with robots, but only thirty-two percent support creation of Federal Robotics Commission).

178. Andrew Tutt, *An FDA for Algorithms*, 69 ADMIN. L. REV. 83, 83 (2017).

179. *Id.* at 106–07.

180. *Id.* at 108.

181. Deirdre K. Mulligan & Kenneth A. Bamberger, *Procurement as Policy: Administrative Process for Machine Learning*, 34 BERKLEY TECH. L.J. 773, 773–74 (2019).

good starting point for validation of algorithms embedded in machine learning systems.[182] The EEOC guidelines, however, are used after the fact, to adjudicate claims of disparate impact discrimination. The proposed machine learning criteria would be used before systems are deployed. Three criteria would be employed: (1) "design should expose built-in values"; (2) "design should trigger human engagement"; and (3) "design should promote contestation about social and political values."[183] The problem with these suggestions is that they almost certainly would result in endless delay before machine learning is deployed as part of decision systems; in other words, they would provide a political level for blocking the new technology.

Mark Lemley and Bryan Casey have probed the utility and limitations of traditional legal measures to control robots.[184]

> In some cases, orders might require robots to make their algorithms perform less well. An injunction preventing the police from taking gender into account in predicting criminality may make it harder to predict who will commit crimes. We might nonetheless want to order it, either to counteract existing bias reflected in the training data or simply because recognizing gender differences in criminality violates a constitutional norm even if the differences are real. But in doing so we are departing from the real world, ordering companies to train their robots to make decisions based on the society we would like to have rather than the one we actually have.[185]

Others, including Bill Gates, have proposed to tax robots, frankly acknowledging that the purpose of such a tax is to discourage automation that will displace workers.[186] They advance two arguments to support their proposals: that the government loses payroll taxes when workers are displaced, and that the current tax code incentivizes automation even when it does not benefit the business investing in it.[187] Such proposals fly in the face of the

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182. *Id.* at 834–35.

183. *Id.* at 846–50 (original capitalization omitted).

184. Mark A. Lemley & Bryan Casey, *Remedies for Robots*, 86 U. CHI. L. REV. 1311, 1315–16 (2019) (evaluating possible legal measures to control or punish misbehaving robots, including a "robot death penalty").

185. *Id.* at 1388.

186. *See* Kevin J. Delaney, *The Robot That Takes Your Job Should Pay Taxes, Says Bill Gates*, QUARTZ (Feb. 17, 2017), https://qz.com/911968/bill-gates-the-robot-that-takes-your-job-should-pay-taxes/ (reporting interview with Bill Gates in which he proposed a tax to slow the pace of automation).

187. *See* Eduardo Porter, *Don't Fight the Robots. Tax Them.*, N.Y. TIMES (Feb. 23, 2019), https://www.nytimes.com/2019/02/23/sunday-review/tax-artificial-intelligence.html (assessing Gates proposal to tax automation in light of tax incentives to automate; acknowledging difficulties of a direct robot tax but suggesting that tax incentives for automation might be reduced instead).

generally recognized need of any economy to innovate to stay prosperous,[188] and are ironic in the mouths of people like Bill Gates or Elon Musk.[189] One wonders what their reaction would be to a proposal to impose a surtax on small computers or on electric cars, both of which had and are having a substantial job-displacement effect.[190]

> "'It's one of the more harebrained ideas,' [is one commentator's reaction.] 'Just about every aspect of it's wrong' . . . [T]he country should be trying to improve flagging productivity growth, not inhibiting it. 'The problem that we're ostensibly trying to fix isn't there.'"[191]

1. The Need for Risk-Based Regulation

The benefits of a market economy occur only when the government abstains from interfering in markets unless market failure exists. Market failure is of two types: the inability of markets to protect against injury because of externalities; and the failure of markets to preserve competition, which is the characteristic that produces all the advantages theoretically associated with markets in the first place.[192]

Despite this precept, instances are legion in which interest groups successfully press legislators and administrative agency personnel to regulate technologies and markets to discourage the use of new technologies in order

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188. Paul Ericksen, *A Robot Tax Is a Very Bad Idea*, INDUSTRYWEEK (Sept. 20, 2019), https://www.industryweek.com/technology-and-iiot/article/22028269/a-robot-tax-is-a-very-bad-idea (arguing that the United States lags in automation and that taxing robots will increase the lag).

189. Musk has not proposed a tax but has proposed a universal basic income to offset job displacement effected by artificial intelligence. *See* Catherine Clifford, *Elon Musk Says Robots Will Push Us to a Universal Basic Income—Here's How It Would Work*, CNBC (Nov. 18, 2016, 11:28 AM), https://www.cnbc.com/2016/11/18/elon-musk-says-robots-will-push-us-to-a-universal-basic-income-heres-how-it-would-work.html.

190. *See* Milton Ezrati, *A Robot Tax Will Help No One and Hurt Many*, FORBES (Oct. 27, 2019, 6:33 PM) https://www.forbes.com/sites/miltonezrati/2019/10/27/a-robot-tax-will-help-no-one-and-hurt-many/#35b16133779f (challenging proposals by Bill de Blasio and others for a tax on robots that displace workers, as determined by a new "Federal Automation and Worker Protection Agency (FAWPA)"; marshaling historical evidence that innovation does not result in net job loss because creation of new jobs compensates for those lost).

191. Richard Rubin, *The "Robot Tax" Debate Heats Up*, WALL ST. J., (Jan. 8, 2020, 10:00 AM), https://www.wsj.com/articles/the-robot-tax-debate-heats-up-11578495608 (quoting and summarizing Dean Baker, co-founder of the Center for Economic and Policy Research, a left-of-center think tank).

192. *See* Cary Coglianese et al., *Seeking Truth for Power: Informational Strategy and Regulatory Policymaking*, 89 MINN. L. REV. 277, 281–82 (2004) (explaining that government regulation is justified by three types of market failure, including lack of competition and externalities); James A. Henderson, Jr., *Learned Hand's Paradox: An Essay on Custom in Negligence Law*, 105 CAL. L. REV. 165, 175 (2017) (explaining that judicial review or regulation can check some kinds of market failure).

to protect the vested positions of incumbents. Such efforts were prominent in the beef industry in the 1930s and 1940s, when the railroads and union-organized trucking companies sought regulation of cattle haulers under the Interstate Commerce Act to limit their competitive threat.[193] Efforts to limit Uber, Lyft and other manifestations of the gig economy in order to protect the interests of taxicab medallion holders are prominent now.[194]

Already, irrational calls exist for regulation of robots and other techniques of industrial automation and for regulation of artificial intelligence on the general ground, entirely unsubstantiated, that allowing markets to guide evolution of these new families of technology will lead to unacceptable levels of job loss or loss of human control over society.[195]

A much better approach is represented by the federal Occupational Safety and Health Administration's (OSHA) initial efforts. It has published guidance for robot safety in industrial workplaces.[196] The guidance suggests beginning with an assessment of the risks posed by the particular robotic system: "The proper selection of an effective robotic safeguarding system should be based upon a hazard analysis of the robot system's use, programming, and maintenance operations."[197]

A focus on the beef industry reveals few risks of increased use of robots in autonomous machinery that might call for government intervention. Cattle herding, treatment, and feeding systems pose little risk to the cattle or to their human supervisors.

OSHA regulations for agriculture, including the beef industry, do little to address the unique risks posed by cattle raising. The regulations address risks posed by machinery and vehicles in any industrial environment and seek to reduce the probability of cutting, catching, and crushing accidents. Some accidents occur on cow-calf operations and feedlots, such as when a cowboy is crushed by a tractor pulling a feed delivery vehicle or gets part of his body caught in a grain auger. Deployment of robots to perform the de-

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193. *See* Perritt, *Twentieth Century Cowboy*, *supra* note 1, at 193 (analyzing railroad, Teamster-union, and major-trucker lobbying to regulate cattle haulers).

194. *See* Henry H. Perritt, Jr., *Don't Burn the Looms—Regulation of Uber and Other Gig Labor Markets*, 22 SMU SCI. & TECH. L. REV. 51, 80–81 (2019) (describing political pressure to regulate ride-hailing enterprises to protect legacy industries).

195. *See* Devin Coldewey, *AI Desperately Needs Regulation and Public Accountability, Experts Say*, TECHCRUNCH (Dec. 7, 2018, 3:44 PM), https://techcrunch.com/2018/12/07/ai-desperately-needs-regulation-and-public-accountability-experts-say/ ("Artificial intelligence systems and creators are in dire need of direct intervention by governments and human rights watchdogs.").

196. OSHA, U.S. DEP'T OF LABOR, OSHA TECHNICAL MANUAL [hereinafter "OSHA TECHNICAL MANUAL"], SECTION IV: CHAPTER 4: INDUSTRIAL ROBOTS AND ROBOT SYSTEM SAFETY, https://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_4.html (last visited July 8, 2020) (assessing risks and summarizing basic safety protocols for factory robots).

197. *Id.* at § I(B)(1).

livery and grain movement tasks would reduce these risks without the need for additional robot-specific regulations. National Institute of Occupational Health and Safety (NIOSH) data show that the vast majority of serious accidents in agriculture occur in conjunction with vehicle rollovers.[198] Substituting autonomous robots for workers riding vehicles will eliminate the source of these accidents.

When cowboys work in proximity to robots, however, the risk of being crushed between the robot and any hard surface is present.[199] Such a risk must be addressed by proximity and pressure detectors on the robot connected so as to stop its motion and cause it to back away when it detects contact with something that might be a human body.[200]

The risks of herding cattle and performing other tasks from horseback are not addressed by existing OSHA regulations, though they are not inconsiderable. Cowboys can break their necks, get skull fractures, or otherwise be injured from being thrown from horses. They can have parts of their body crushed when the horse moves too close to a fence or other obstruction. They can be dragged if one of their feet catches in a stirrup after a fall or a clumsy dismount.

All of these risks exist because the cowboy rides the horse. Robocowboys would not have riders.[201] So no additional safety regulation would be necessary for robot cowboys engaged in herding operations or other equivalent tasks that the cowboys presently do on horseback.

A robot can injure a worker if it becomes active while the worker is performing service or maintenance tasks on it. Thus, it is appropriate for robot safety standards to include a provision for absolute temporary disabling of the robot by someone doing work on it, as by removing a key that

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198. Nat'l Institute for Occupational Safety and Health, *Agriculture Safety*, CENTERS FOR DISEASE CONTROL AND PREVENTION, https://www.cdc.gov/niosh/topics/aginjury/default.htm (last updated Oct. 9, 2019).

199. *See generally* OSHA, *Results for Keyword "Robot," Accident Search Results*, U.S. DEP'T OF LABOR, https://www.osha.gov/pls/imis/AccidentSearch.search?acc_keyword=%22Robot%22&keyword_list=on (searched Aug. 16, 2019) (listing 43 accidents involving robots, including fractured hip when struck by robot, fractured sternum when struck by robot arm, robot crushing & killing worker inside robot work cell).

200. *See* OSHA TECHNICAL MANUAL, SECTION IV, CHAPTER 4 § V(2) (recommending use of "[p]resence-sensing safeguarding devices"); *see also, e.g.*, Michelle Hampson, *Skin-like, Flexible Sensor Lets Robots Detect Us*, IEEE SPECTRUM (Mar. 9, 2020, 4:31 PM), https://spectrum.ieee.org/tech-talk/robotics/robotics-hardware/skin-flexible-proximity-sensor-robots (describing newly developed proximity sensor).

201. Conceivably, the term "robocowboy" could be defined broadly enough to include an ATV or like vehicle ridden by a human cowboy with high levels of automation for navigation, but this article uses a narrower definition, one that includes only wireless vehicles, with the possibility of remote control or complete autonomy.

controls the circuit for its operation.[202] The risk is slightly different from that addressed by blue flagging of rail equipment while it is being serviced.[203] There, the risk is that another person will move the equipment; in the case of the robot, the risk is that the robot itself will move or that someone else will turn it on.

Self-driving trucks, on the other hand, pose risks to drivers and passengers of other vehicles, pedestrians, and persons living near roadways. These risks are similar to those posed by any self-driving vehicle and are perhaps somewhat greater in proportion to the greater mass of a cattle truck as compared to a passenger automobile. The widespread belief that self-driving vehicles are likely in the near-term future has given rise to a robust set of regulatory frameworks for dealing with the new technology.[204] Nothing about self-driving cattle trucks poses risks different from those posed by self-driving vehicles in general, so no additional regulatory initiative is necessary for this aspect of the cattle industry.

2. OSHA Regulation of the Cattle Industry

OSHA has jurisdiction over farmworkers, but OSHA standards for agricultural operations are sparse. They mainly relate to roll-over protection on vehicles[205] and guarding of farm field equipment.[206] Hazards relate to handling of animals and operating of machinery.[207] OSHA has jurisdiction over feedlots, but is relatively inactive in that sector:[208]

> [A]lthough there are few agriculture specific OSHA regulations, the General Duty Clause applies. Therefore, training related to personal pro-

202. *See* OSHA TECHNICAL MANUAL, SECTION IV, CHAPTER 4 § V(7)–(8) (describing risks of robot repair and importance of maintenance).

203. *See* 49 C.F.R. §§ 218.21–.30 (2020).

204. *See USDOT Automated Vehicles Activities*, U.S. DEP'T OF TRANSP., https://www.transportation.gov/AV (last updated April 16, 2020) (portal for U.S. Department of Transportation regulatory activities related to autonomous vehicles).

205. 29 C.F.R. §§ 1928.51–.53 (2020).

206. 29 C.F.R. § 1928.57 (2020).

207. *See, e.g.*, UNIV. OF IOWA, IOWA FACE REPORT CASE ID 2011 IA 039 (Dec. 10, 2013), https://face.public-health.uiowa.edu/Reports/PDF-Reports/2011IA039.pdf (reporting on fatal accident on cow-calf operation; minor victim was ejected from bucket of front-end loader and hit head).

208. *See generally* Heather Smith Thomas, *Keeping on Top of OSHA Regulations*, PROGRESSIVE CATTLE (June 24, 2016), https://www.progressivecattle.com/topics/facilities-equipment/keeping-on-top-of-osha-regulations (providing an overview of OSHA coverage of cow-calf operations and feedlots); OSHA, *Inspection Detail: Inspection: 314059684 - Dl Cattle Trading Llc Dba Dl Cattle Llc & Dl Farms*, U.S. DEP'T OF LABOR, https://www.osha.gov/pls/imis/establishment.inspection_detail?id=314059684.0 (last visited July 9, 2020) (summarizing penalties imposed after feedlot employee was asphyxiated in a grain bin).

> tective equipment, machine guarding, lock-out/tag-out, confined space, vehicle safety, and fall protection is still relevant. Ensuring that someone on the feedyard is trained in cardiopulmonary resuscitation (CPR) and first aid is also required, since most feedyards are not in close proximity to an emergency facility. Finally, if the feedyard has more than 10 employees then they are bound by the OSHA recordkeeping rules and are required to maintain OSHA 300 logs documenting any serious occupational injuries or illnesses; consequently, workers, particularly those in supervisory roles, should be trained on how to complete and maintain these records.[209]

Industry groups hold seminars and workshops promoting feedlot safety.[210] "We hear about employees being run over by feed trucks, dragged by horses, thrown off ATVs or pinched while working cattle."[211]

"There are currently no specific OSHA standards for the robotics industry. [OSHA's website] highlights OSHA standards and documents related to robotics."[212] OSHA has published guidelines for industrial robot safety.[213] While these guidelines do not have the legal force of blackletter regulations promulgated through notice-and-comment rulemaking,[214] they are useful because they begin with a risk-analysis framework and proceed to identify the principal ways in which robots can be designed and deployed so as to mitigate risk. It does not matter that they are aimed at industrial robots instead of robots used in beef production. Their level of abstraction accommodates both, and their classification and discussion of risks is broad

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209. Athena K. Ramos et al., *A Preliminary Analysis of Immigrant Cattle Feedyard Worker Perspectives on Job-Related Safety Training*, SAFETY, Sept. 2018, at 2, https://www.mdpi.com/2313-576X/4/3/37/htm (summarizing applicability of OSHA regulations).

210. *See, e.g.*, TEX. CATTLE FEEDERS ASS'N: FEEDYARD SAFETY ROUNDTABLE, RECOMMENDATIONS TO IMPROVE WORKER SAFETY ON FEEDYARDS (Feb. 19, 2015), https://www.unmc.edu/publichealth/cscash/_documents/Feedyard-Worker-Safety-Roundtable-Summary.pdf (recommending greater attention to cattle feedlot safety; content entirely focused on process rather than specific risks); Don Tyler, *Feedyard Accidents and the Risks to Your Bottom Line*, FEEDLOT, https://feedlotmagazine.com/feedyard-accidents-and-the-risks-to-your-bottom-line/ (last visited July 19, 2020) (noting greater levels of OSHA enforcement of standards against feedlots).

211. Tyler, *supra* note 210. *See also* Gordon Moore, *Feedyard Safety a Day-In, Day-Out Effort*, BEEF (June 28, 2012), https://www.beefmagazine.com/cattle-handling/feedyard-safety-day-day-out-effort (listing loss of an arm from a grain augur, loss of life from heifer ramming gate into farmer with loaded syringe in pocket, horse killing cowboy chasing a steer by throwing him over fence).

212. OSHA, *Robotics Standards*, U.S. DEP'T OF LABOR, https://www.osha.gov/SLTC/robotics/standards.html (last visited July 19, 2020).

213. OSHA TECHNICAL MANUAL, SECTION IV, CHAPTER 4.

214. The introduction to the Technical Manual makes it clear that the contents of the Manual do not have the same effect as formal OSHA standards or regulations. OSHA TECHNICAL MANUAL, INTRODUCTION.

enough to accommodate the risks associated with robocowboys in feedlots and on the range.

The guidelines classify robot-related risks into four categories: (1) impact or collision accidents; (2) crushing and trapping accidents; (3) mechanical-part accidents; and (4) "other."[215] A collision accident is what its title suggests.[216] Trapping and crushing accidents include situations in which human body parts are trapped between the robot or its appendage and an unyielding object, resulting in a crushing injury.[217] Mechanical-part accidents include those in which a broken machine part becomes a projectile.[218] The "other" category includes, among other things, pressurized fluid hazards, electrocution dangers, and radiofrequency interference.[219]

The guidelines go on to identify seven sources of risk: (1) human errors; (2) control errors; (3) unauthorized access; (4) mechanical failures; (5) environmental sources; (6) power systems; and (7) improper installation.[220] Control errors are "[i]ntrinsic faults within the control system of the robot, errors in software, electromagnetic interference," and faults in sensors and actuators.[221] Environmental sources include external sources of electromagnetic interference.[222] One also might include deliberate sabotage in the environmental sources category, even though the OSHA guidelines do not mention it.

The Guidelines require that robots comply with OSHA's rules for Selection and Use of Work Practices[223] and its Control of Hazardous Energy (Lockout/Tagout) rules.[224] The Guidelines say the risk assessment should occur at each stage of robot development,[225] that one or more safeguarding devices such as presence-sensing and mechanical limiting devices and fixed barriers should be employed,[226] that awareness devices such as flashing lights or horns be considered,[227] and that special protections be afforded to robot teachers and operators,[228] among other things.[229]

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215. OSHA TECHNICAL MANUAL, SECTION IV, CHAPTER 4 § III(I)(1)–(4).
216. *Id.* at § III(I)(1).
217. *Id.* at § III(I)(2).
218. *Id.* at § III(I)(3).
219. *Id.* at § III(I)(4).
220. *Id.* at § III(II)(1)–(7).
221. OSHA TECHNICAL MANUAL, SECTION IV, CHAPTER 4 § III(II)(2).
222. *Id.* at § III(II)(5).
223. 29 C.F.R. § 1910.333 (2020).
224. 29 C.F.R. § 1910.147 (2020); OSHA TECHNICAL MANUAL, SECTION IV, CHAPTER 4 § V(10).
225. OSHA TECHNICAL MANUAL, SECTION IV, CHAPTER 4 § V(1).
226. *Id.* at § V(2).
227. *Id.* at § V(3).
228. *Id.* at § V(4)–(5).
229. *Id.* at § V(6)–(9) (identifying other risk-reduction steps).

OSHA does not have jurisdiction over the trucking industry[230] and does not regulate owner-operators. It does, however, regulate the health and safety of employees who work at loading docks and similar truck interfaces with shippers and consignees.[231]

3. European Union (EU) Approach

European law regulates robots indirectly, by regulating their "decision systems" and the data that feeds the machine learning that constructs decision systems. Article 15 of the European data directive requires that decision systems be able to explain why they made a decision.[232]

Sophisticated machine learning systems may be unable to do that. The most rigorous explanation would be that "the system statistically evaluated some 200,000 examples and made its most informed guess." That is not a very useful.[233]

The European Commission released a white paper in early 2020 that outlines future EU regulation of machine learning.[234] It purports to adopt a

230. *See* OSHA, *Trucking Industry: Other Federal Agencies*, U.S. DEP'T OF LABOR, https://www.osha.gov/SLTC/trucking_industry/otherfed.html#FMCSA (last visited July 19, 2020) (OSHA-provided links to DOT motor carrier regulations related to driver health and safety).

231. OSHA, *Trucking Industry: Overview*, U.S. DEP'T OF LABOR, https://www.osha.gov/SLTC/trucking_industry/ (last visited July 19, 2020) ("OSHA does not regulate self-employed truckers.").

232. Article 15 of the European Data Protection Regulation, Regulation (EU) 2016/679, gives data subjects the right to know not only what data about them is being processed, but also about "the existence of automated decision-making, including profiling, referred to in Article 22(1) and (4) and, at least in those cases, meaningful information about the logic involved, as well as the significance and the envisaged consequences of such processing for the data subject." Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the Protection of Natural Persons with Regard to the Processing of Personal Data and on the Free Movement of Such Data, and Repealing 95/46/EC (General Data Protection Regulation), art. 15(1)(h), 2016 O.J. (L 119) 43.

233. *See* Mark MacCarthy, *How to Address New Privacy Issues Raised by Artificial Intelligence and Machine Learning*, BROOKINGS: TECHTANK (Apr. 1, 2019), https://www.brookings.edu/blog/techtank/2019/04/01/how-to-address-new-privacy-issues-raised-by-artificial-intelligence-and-machine-learning/ (summarizing possible requirements that machine learning algorithms be explainable and noting the difficulties with such a requirement); DAVID GUNNING, DARPA, EXPLAINABLE ARTIFICIAL INTELLIGENCE 2–17, https://www.cc.gatech.edu/~alanwags/DLAI2016/(Gunning)%20IJCAI-16%20DLAI%20WS.pdf (explaining tradeoff between explainability and accuracy in machine learning; describing how machine learning systems can be made to explain their conclusions).

234. *Commission White Paper on Artificial Intelligence: A European Approach to Excellence and Trust*, at 9, COM (2020) 65 final (Feb. 19, 2020) https://ec.europa.eu/info/sites/info/files/commission-white-paper-artificial-intelligence-feb2020_en.pdf (setting out seven key requirements for regulating AI).

risk-based approach[235] but blocks use of some machine-learning systems until they obtain regulatory approval.[236] The paper describes the risks of machine learning systems as evading social control mechanisms.[237] Regulators would scrutinize the data sets used for machine learning.[238]

Some scholars have suggested that the EU approach may not achieve much.[239]

4. *Performance-Based Regulation*

When the data establish that a concrete risk exists, one serious enough to warrant government intervention, the proponents of a regulation should be able to establish that the content of the regulation they contemplate would reduce the risk. Then they must write a regulation (or statutory requirement) that is performance-based, not one that establishes the engineering details of system design.[240] For example, a regulation designed to reduce the risk of a robocowboy crushing a human cowboy or maintainer should provide that the robot must be able to detect contact with a human body and stop and back away. It should not prescribe the particular sensor technology or servomechanisms required to accomplish the function. The NHTSA requirement for electronic stability control systems on heavy trucks is a good example of a performance standard.[241]

Regulatory requirements for robots are not unlike regulatory requirements for drones. Both involve high degrees of autonomy and sophisticated computer hardware and software to accomplish their missions. The Office of Management and Budget requires federal agencies to prefer performance

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235. *Id.* at 17 (embracing a risk-based approach to regulation of AI).

236. *Id.* at 23 (proposing "prior conformity assessment"—pre-approval by regulatory bodies before deployment—for high-risk systems).

237. *Id.* at 11–12 (describing risks of opacity of machine learning, allowing adverse effects without normal social control mechanisms).

238. *Id.* at 19 (suggesting requirements that "AI systems [be] trained on data sets that are sufficiently broad and cover all relevant scenarios needed to avoid dangerous situations," and that documentation describe the training data set and training methodologies, including validation criteria).

239. *See* Andrew D. Selbst & Solon Barocas, *The Intuitive Appeal of Explainable Machines*, 87 FORDHAM L. REV. 1085 (2018) (discussing limitations of efforts to make the results of machine learning systems explainable); *see id.* at 1107–09 (discussing limitations of EU GDPR section 15).

240. *Accord* Henry H. Perritt & Albert J. Plawinski, *Making Civilian Drones Safe: Performance Standards, Self-Certification, and Post-Sale Data Collection*, 14 NW. J. TECH. & INTELL. PROP. 1, 11–13 (2016).

241. *See* 49 C.F.R. § 571.136 S4 (2020) (defining electronic stability control system in terms of attributes and performance-defined "means").

standards:[242] "To the extent feasible, agencies should specify performance objectives, rather than specifying the behavior or manner of compliance that regulated entities must adopt."[243]

The final report of the Clinton Administration's White House Commission on Aviation Safety and Security said, "all new rules should be rewritten as performance-based regulations."[244] The FAA recognizes the superiority of performance standards over design standards, particularly in the drone context:

> It is well understood that regulations that are articulated in terms of the desired outcomes (*i.e.*, "performance standards") are generally preferable to those that specify the means to achieve the desired outcomes (*i.e.*, "design" standards). According to Office of Management and Budget Circular A–4 ("Regulatory Analysis"), performance standards "give the regulated parties the flexibility to achieve the regulatory objectives in the most cost-effective way." Design standards have a tendency to lock in certain approaches that limit the incentives to innovate and may effectively prohibit new technologies altogether. The distinction between design and performance standards is particularly important where technology is evolving rapidly, as is the case with small UAS.[245]

In the air and water pollution contexts, for example, a performance standard can be set at the effluent levels achievable by the best available technology, while leaving the choice of the particular technology to be used to the regulated entity.[246]

Environmental regulators set performance standards based on the level of performance a particular technology can deliver. The ultimate standard does not require use of that technology, but the link between them ensures

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242. *See* Jay P. Kesan & Rajiv C. Shah, *Shaping Code*, 18 HARV. J.L. & TECH. 319, 340–42 (2005) (distinguishing performance standards, design standards, and "best available technology standards" and briefly summarizing criticisms of each).

243. OFFICE OF INFO. & REGULATORY AFFAIRS, REGULATORY IMPACT ANALYSIS: A PRIMER 3, https://www.whitehouse.gov/sites/default/files/omb/inforeg/regpol/circular-a-4_regulatory-impact-analysisa-primer.pdf [https://perma.cc/LQT6-GBPU] (last visited July 19, 2020).

244. WHITE HOUSE COMM'N ON AVIATION SAFETY AND SECURITY, FINAL REPORT TO PRESIDENT CLINTON (1997), http://fas.org/irp/threat/212fin~1.html [http://perma.cc/8DYQ-4QW8]. The Commission was established by Executive Order 13015 on August 22, 1996. *Id.*

245. Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. 9544, 9552 (proposed Feb. 23, 2015).

246. *See* Richard L. Revesz & Allison L. Westfahl Kong, *Regulatory Change and Optimal Transition Relief*, 105 NW. U. L. REV. 1581, 1597 (2011) (explaining that performance standards allow for technological innovation, while design standards do not, in the context of pollution regulation); *see also* Timothy F. Malloy, *The Social Construction of Regulation: Lessons From the War Against Command and Control,* 58 BUFF. L. REV. 267, 315–19 (2010) (arguing superiority of performance standards and evaluating how they are used by EPA in regulating air pollution).

that there is at least one way to comply with the performance standard. The same approach is useful in developing performance standards for robocowboys. The problem with deriving a performance standard from the performance of an actual technology is that it can have the effect—intended or unintended—of locking in proprietary technology. Much of the law of standard-setting has evolved from deliberate attempts to set a standard to confer a proprietary advantage.[247] Many of the controversies in contemporary standard setting relate to designers' reluctance to give up their intellectual property and their competitors' opposing unwillingness to pay their competitors to license their intellectual property in order to comply with the standard.[248]

One disadvantage of any performance-based regulatory standard is unpredictability. A regulatee has flexibility to choose how to meet the performance standard, but he has no guarantee that the regulator or a court hearing a civil claim will reach the same conclusion, after the fact, about the most appropriate way to meet the standard. Uncertainty can be reduced by publication of a non-exclusive safe harbor. A regulatee may apply different standards at its discretion, but if it seeks more certainty, it can apply the published, safe harbor standard. By proving that it followed the published standard, it has protection against being found in violation or being held liable. Antitrust guidelines published by the Department of Justice[249] are a good example of this approach.

5. *Regulation of Texas, a Robo-Cattle-Truck*

In January 2020, the U.S. Department of Transportation published a document inviting comment on the Department's plans to regulate and promote autonomous vehicle technologies.[250] The report emphasizes non-

247. *See* Radiant Burners, Inc. v. Peoples Gas Light & Coke Co., 364 U.S. 656, 658–60 (1961) (holding that complaint alleging refusal to give seal of approval to plaintiff's gas burner for anti-competitive reasons stated antitrust claim); Cryptography Research Inc. v. Visa Int'l Serv. Ass'n, No. C 04–04143 JW, 2008 WL 5560873, at *3 (N.D. Cal. Aug. 13, 2008) (citing *Radiant Burners* in support of denial of motion to dismiss claim that "standard setting organization" denied certification "for reasons unrelated to the objective qualities of the technology").

248. *See* Martin Campbell-Kelly, *Not All Bad: An Historical Perspective on Software Patents*, 11 MICH. TELECOMM. & TECH. L. REV. 191, 229–30 (2005) (discussing controversy over public key encryption and RSA software patent).

249. ANTITRUST DIV., U.S. DEP'T OF JUSTICE, ANTITRUST DIVISION MANUAL CH. VII (5th ed. 2015) http://www.justice.gov/sites/default/files/atr/legacy/2015/05/13/chapter7.pdf [http://perma.cc/8STB-A42R].

250. *USDOT Automated Vehicles Activities*, U.S. DEP'T OF TRANSP., https://www.transportation.gov/AV (last updated Apr. 16, 2020) (referring to *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0* (AV 4.0), https://www.transportation.gov/av/4).

binding consensus standards and disavows pre-government approval of autonomous vehicles.[251] Twenty-nine states have enacted autonomous vehicle legislation,[252] and most are considering some form of legislative action.[253] The Secretary of Transportation has authority to determine that federal law preempts a state law or regulation pertaining to commercial motor vehicle safety.[254]

The content of safety regulation for robocowboys will be similar, in many respects, to the regulations for self-driving vehicles that operate on roads. Such self-driving vehicles must have algorithms that place limitations on vehicle handling. Vehicles with drivers depend on the driver's skill to avoid things like rollovers or skids occasioned by overly abrupt control (steering) inputs.[255] Such limitations are particularly important for self-driving cattle trucks, because the weight of the cargo, combined with the possibility that the cattle will change position, can create challenging center of gravity problems.

The National Highway Traffic Safety Administration (NHTSA) enforces several vehicle safety standards applicable to heavy trucks that con-

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251. NAT'L SCI. & TECH. COUNCIL & U.S. DEP'T OF TRANSP., ENSURING AMERICAN LEADERSHIP IN AUTOMATED VEHICLE TECHNOLOGIES: AUTOMATED VEHICLES 4.0 29–30 (2020).

252. *Autonomous Vehicles: Self-Driving Vehicles Enacted Legislation*, NAT'L CONF. OF STATE LEGISLATURES (Feb. 18, 2020), https://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx (reporting state legislative activity through late January 2020).

253. *Id.* For example, the District of Columbia Autonomous Vehicles Act of 2012 would be amended by a bill under consideration in committee as of late 2019. Council B. 248, 2019 Council (D.C. 2019). Autonomous vehicles must be registered to operate on public roadways. *Id.* §2(b), (amending D.C. Code § 50-2352). Registration is allowed only if the vehicle is "capable of operating in compliance with [general] traffic laws . . . and traffic control devices" and if it has a safety system that can bring it to "a minimal risk condition" in the event of a malfunction. D.C. Council B. 248 § 2(b), (amending D.C. Code § 50-2352(b)(2)(C)–(B)). The existing statute defines "motor vehicle" as a "vehicle propelled by an internal-combustion engine, electricity, or steam." D.C. Code § 50-1501.01(1) (2020). It defines "autonomous vehicle" as "a vehicle capable of navigating District roadways and interpreting traffic-control devices without a driver actively operating any of the vehicle's control systems." D.C. Code § 50-2351(1) (2020). The context suggests that the omission of the word "motor" before the word "vehicle" is of no significance. The bill makes no material changes to these definitions.

254. 49 U.S.C. § 31141; U.S. DEP'T OF TRANSP., FED. MOTOR CARRIER SAFETY ADMIN., LEGAL OPINION OF THE OFFICE OF THE CHIEF COUNCIL ON APPLICABILITY OF PREEMPTION DETERMINATIONS TO PENDING LAWSUITS 1 (Mar. 22, 2019), https://www.fmcsa.dot.gov/safety/fmcsa-legal-opinion-applicability-preemption-determinations-pending-lawsuits.

255. Aircraft pilots, for example, are trained and required to monitor aircraft loading before flight to assure that center of gravity is within allowable limits and to limit control forces so that load factors from angular velocity do not exceed other load factors (more often related to structural failure than "tipping" of a land vehicle).

ceptually are suitable for self-driving trucks.[256] Another standard might be a model for smaller robocowboys.[257] Straightforward engineering calculations permit determining the tipping moment as a function of the center of gravity of a vehicle, given its basic dimensions. Other straightforward engineering calculations permit calculating the angular velocity[258] at which the tipping moment will be exceeded.

Cattle truck design standards can reduce the risk of rollover by specifying maximum turning inputs as a function of center of gravity and speed. Such limitations can be incorporated relatively easily into the autopilot for self-driving cattle trucks, if the cattle trailer has sensors that permit determining its center of gravity once cattle are loaded. Alternatively, the center of gravity of the cattle truck can be limited by designing compartments and chutes for filling them to restrict the position of cattle of different weights.

An engineering-standards approach would specify the algorithms to prevent tipping and the sensors required to determine center of gravity. A performance-based approach would simply specify that a cattle hauling semi-trailer must have a control subsystem comprising appropriate sensors and algorithms that prevent tipping of the trailer at all likely loads and speeds.[259] The regulation could back up the performance standard in any one of several ways, ranging from most to least intrusive. The most intrusive approach would require that the vehicle be submitted for testing by an administrative agency before it can be placed on the market. The second approach would require that the vehicle manufacturer test the vehicle according to test specifications by the agency[260] and submit those test results to the agency for review and approval before the vehicle is marketed. A third approach would require the manufacturer to perform tests appropriate to determine compliance with the performance standard and would require no data submission or agency review before marketing.

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256. *See* Air Brake Systems, 49 C.F.R. § 571.121 S5.3.1 (2020) (requiring reduced stopping distance for truck trailers when loaded to maximum gross weight); Electronic Stability Control Systems for Heavy Vehicles, 49 C.F.R. § 571.136 (2020) (proposing electronic stability control for truck-tractors to reduce rollovers and severe understeer and oversteer conditions that lead to loss of control).

257. Low Speed Vehicles, 49 C.F.R. § 571.500 (2020) (establishing standard for golf carts and similar vehicles operated on public roads).

258. Angular velocity is a function of the radius of return and the velocity of the vehicle.

259. The existing NHTSA standard for truck electronic stability systems is a good example. *See* 49 C.F.R. § 571.136 S4 (2020) (specifying capabilities in definition of system).

260. *See, e.g.*, 49 C.F.R. § 571.136 S5.3.3 (2020) ("Roll Stability Control Test. During each series of eight consecutive test runs for the determination of roll stability control (see S7.7.3) conducted at the same entrance speed, the vehicle must satisfy the criteria of S5.3.3.1, S5.3.3.2, S5.3.3.3, and S5.3.3.4 during at least six of the eight consecutive test runs.") (NHTSA standard for electronic stability control systems for heavy trucks); *id.* S6.2.4 (prescribing road conditions for tests).

The least intrusive approach would simply impose a performance standard and leave it to the manufacturer to prove that it had met the standard in any lawsuit resulting from an accident or enforcement proceeding.

6. *Agency Jurisdiction*

As regulation of robots increases, as it surely will, the question of agency jurisdiction arises with respect to robots used in the cattle industry. Now, OSHA, USDA, NHTSA, and the Federal Motor Carrier Safety Administration (FMCSA) each have a piece of the regulatory action. NHTSA, acting in consultation with FMCSA, both within the United States Department of Transportation, has authority to regulate truck safety.[261] Some commentators have proposed a new agency to regulate robots of all kinds.[262]

The choice among agencies should be driven by an assessment of the agency's expertise and of the political environment within which each one operates.

OSHA knows more about occupational safety and health in general than any other agency, but its focus historically has been on manufacturing and the construction industries, with little involvement in agriculture. Its politics are shaped by organized labor and big business trade associations led by executives of major corporations.

The Department of Agriculture knows more about agriculture than any other agency, but its focus has not historically been on worker safety. It is, however, in a good position to assess the relative impact of different regulatory requirements on productivity in the cattle industry. Its politics are shaped by the farm lobby, in which cattle interests play an influential role.[263]

FMCSA has more expertise on how road vehicles operate than any other agency. It already is deeply involved in assessing regulatory strategies for self-driving automobiles and trucks.[264] It is likely to retain this jurisdic-

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261. 49 U.S.C. § 30111 (2020) (authorizing Secretary of Transportation to prescribe motor vehicle safety standards); *id.* § 30112(a)(1) (prohibiting manufacture, sale, or import of vehicles not meeting safety standards); 49 C.F.R. § 1.95 (2020) (delegating to National Highway Traffic Safety Administrator authority under chapters 301, 303, 321, 323, 325, 327, 329, and 331 of title 49, United States Code); *id.* § 1.95(c) (delegating concurrent authority with Federal Motor Carrier Safety Administrator to promulgate commercial motor vehicle safety standards under subchapter III of chapter 311 of title 49, United States Code); *id.* § 1.87 (delegating to Federal Motor Carrier Safety Administrator authority under subtitle IV, part B of title 49, United States Code).

262. *See supra* notes 161–67 and accompanying text.

263. See *Agency Profile: Dept of Agriculture*, OPENSECRETS.ORG: CTR. FOR RESPONSIVE POL., http://www.opensecrets.org/federal-lobbying/agencies/summary?cycle=2019&id=023, (last visited Oct. 28, 2020).

264. See *Safe Integration of Automated Driving Systems-Equipped Commercial Motor Vehicles*, FED. MOTOR CARRIER SAFETY ADMIN. (FMCSA), https://www.fmcsa.dot.gov/

tion for self-driving cattle trucks and would have a logical argument that its jurisdiction should be extended to other robotic vehicles elsewhere in the cattle industry. The agency's policies are shaped mainly by trucking interests, the Teamsters Union, and vehicle manufacturers, especially the major automobile companies.

C. Robocowboy Specifics

Consistent with a risk-based approach to regulation, regulation of robocowboys should begin by assessing the risks they present.[265] Section IV.B.5 already has considered the risks and appropriate regulatory approaches for Texas, the robotic cattle truck. The following paragraphs consider Dakota, the range robot, and Montana, the feedlot robot.

Risk assessment for robocowboys involves superimposing the OSHA risk framework on the two environments in which robot cowboys would operate: the range, and the feedlot. Collision accidents are much more likely in the feedlot environment than on the range, but in either case the probability of such accidents occurring depends on whether human cowboys are operating in proximity to the robot cowboys. This is unlikely on the range and may not be likely in feedlot environments, depending on how the work is organized. Trapping and crushing accidents are much more likely in feedlot environments where both robot cowboy and any humans working near it are surrounded by unyielding objects such as fences. Even in feedlots, however, the risk of this type of accident, like collision accidents, depends on whether the work is organized so as to place humans in proximity to cowboys.

With respect to the proximity between humans and robots, one must consider not only the ordinary course of work, but also the situation in which a robot malfunctions and a human must approach to fix it. Many ac-

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newsroom/safe-integration-automated-driving-systems-equipped-commercial-motor-vehicles (ANPRM) (last visited Oct. 28, 2020).

265. This risk assessment considers only the risks posed by Dakota and Montana, not those posed by Texas. Texas is a self-driving truck, and the risks posed by that kind of robot are pretty well understood and are the subject of an emerging body of regulation at the Department of Transportation.

A complete assessment would include not only risks resulting from use of robocowboys, but also the risk avoided by their use. "In the US tractor related accidents continue to be the leading cause of farm worker fatalities. [T]aking the human out of the cab reduces the risk of injury or death on the job and increases overall job satisfaction." *Future of Farming*, BEAR FLAG ROBOTICS, bearflagrobotics.com/#service (last visited July 17, 2020). Cargill promotes the use of its Cowboy Robot largely on the grounds that it avoids the risk of injury to human workers, who can be removed from close contact with the cattle, when the robot is used. *See Meet the Robot That's Making Cattle Herding Safer*, CARGILL (Oct. 18, 2018), https://www.cargill.com/story/meet-the-cowboy-robot-thats-making-cattle-herding-safer.

cidents in both farm and factory environments occur when someone is repairing a machine and it unintentionally begins to move.[266]

All of the sources of risk identified in the OSHA guidelines can occur with robocowboys. Whether the robocowboys' control systems work as intended is not all that different an issue from whether control systems on industrial robots work as intended. The nature of the particular software bugs would be different, of course—they would be more likely to be associated with navigation in cowboy robots, which are mobile, unlike most industrial robots. On the other hand, control and propulsion software in robocowboys is just as likely to suffer from programming and execution errors as their counterpart systems in industrial robots.

Consider the herdAStraggler function, the Swift code for which is set forth in the Appendix. If a routine like this did not include a command to stop the robot's movement when it gets near the herd, a robot programmed with it might crash into the herd while chasing a stray.

The Cargill cowboy robot weighs 450 pounds,[267] and the robocowboy sketched in this article will probably weigh about the same. Its top speed needs to exceed that of a stampeding beef—between nineteen and twenty miles an hour.[268] A 450-pound robot moving at that speed has sufficient momentum to cause a considerable amount of damage if it collides with a human being, an animal, or an inanimate object. Aside from collisions, however, it is hard to imagine what the robocowboy might do that involves a significant risk of harm.

The likelihood of a collision depends upon the robocowboy being misprogrammed, for example, not being programmed to stop or adjust speed when it gets close to a stray or to the herd or the robocowboy running away, as frequently happens with small drones.

Thus, two physical environments are appropriate to understand the risks further: the feedlot and the range. It doesn't matter how big the range is. The relative movement of herd, stray, and robot are the same regardless of whether one is talking about an enclosed pasture of a dozen or so acres,

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266. "[M]any robot accidents do not occur under normal operating conditions but, instead during programming, program touch-up or refinement, maintenance, repair, testing, setup, or adjustment. During many of these operations the operator, programmer, or corrective maintenance worker may temporarily be within the robot's working envelope where unintended operations could result in injuries." OSHA TECHNICAL MANUAL, SECTION IV, CHAPTER 4 § I(A)(1). *See also* Schuh v. Fox River Tractor Co., 218 N.W.2d 728, 731–32 (Wis. 1974) (describing accident during farm-machine repair resulting in leg amputation).

267. Gilda V. Bryant, *Cargill's New Robot Benefits Cattle Industry*, PROGRESSIVE CATTLEMAN (Feb. 22, 2019), https://www.progressivecattle.com/topics/facilities-equipment/cargill-s-new-robot-benefits-cattle-industry.

268. *See Cow Speed! How Fast Do Cows Run? (A Partial Answer)*, https://www.crazyforcows.com/fow/how-fast-do-cows-run.shtml (reporting guesses of fifteen to twenty miles per hour).

or a completely open range of thousands. The herd, its strays, and robocowboys will be interacting in a relatively limited area, compared with the whole.

The risks are considerably greater in the feedlot environment, compared to the range. This is because feedlots comprise an arrangement of confined pathways and holding areas. In any of these spaces, a human cowboy or an animal will be restricted in its ability to get away from an out-of-control robot by the fencing that defines the feedlot. Anyone who has ever been to a cattle auction recognizes how vulnerable the herd inside the display area is. Auction spaces typically provide a small escape area which the herder can get into if the animal is showing off Pratt and Sam.

On the open range, a runaway robot poses a threat to human cowboys and animals alike, but they have a much better chance of escaping than they would in a feedlot. Even on the range, however, the robot will be designed to have a speed exceeding that of the cattle and perhaps that of a human cowboy on horseback or in a gator, which would limit the options for escape, unless the cattle or the mounted human cowboy are more agile than the robot.

The risk to third parties, conversely, is less in the feedlot environment than on the range. The fences that comprise a feedlot likely are stout enough to block an out-of-control robot. Its momentum will be less than that of a stampeding steer, because even though their speeds are comparable, a steer weighs much more. So, if a fence is strong enough to contain the cattle, it will be strong enough to contain a runaway robot. Third parties, in any reasonable security situation, will be outside the feedlot fences and thus protected from harm by the robot.

This is not true on the range. The possibility that third parties might be at risk from a runaway robot depends not on the proximity of the third party to the herd, but on the robot's range and endurance. Any third party within that range is at risk.

The risk that animates most public discussion of robots is not a risk of injury, within OSHA's jurisdiction, but the risk of displacement of human workers: Kirby and Bennington, in this running story of robocowboys. Separately, robocowboys create risks to the cattle they are designed to herd and otherwise manage.[269]

So, then the question is: what kind of regulatory strategies would mitigate these risks? Evaluation of industrial robots has led to three basic strategies: (1) requiring the robot to operate in a contained area from which human beings are excluded, (2) requiring human beings to engage in certain

269. It is unlikely that anyone would design a robocowboy to abuse animals or to abuse the environment. But their use may call into question long-standing practices, such as cattle prods, that have been accepted when humans employ them.

conduct when they are within range of the robot, and (3) requiring that the robot be designed and programmed to engage in certain conduct to reduce risk.[270]

The last of the strategies would use a computer program code to enforce the limitations. The first two strategies rely on conventional and long-established construction and factory-design requirements and compliance techniques, and equally long-standing human compliance with rules.

Existing OSHA rules are useful starting points for the first and second regulatory strategies. The existing OSHA robot rules deal with enclosures for robots. Those rules and many other factory rules relating to guarding dangerous machinery are pertinent as well.

Regulating through code under the third strategy invites analogies to airworthiness certification of aircraft navigation and control systems and of discussion of performance standards for drone behavior.

Ultimately, however, just because robot cowboy regulation is feasible and can be conceptualized along these lines does not mean that such regulation should be promulgated. Whether such regulation occurs should depend on a cost-benefit analysis—a weighing of the costs of compliance against the benefits, in terms of risk reduction. That kind of cost-effectiveness analysis is a regular feature of federal agency regulation of all kinds.[271] In the feedlot environment, requiring that robots operate in an enclosure imposes no costs for a well-designed feedlot. Strong enclosures are a part of basic feedlot design. However, requiring that robots operate only in enclosures is infeasible on the range. Any such requirement for robot cowboys, if universal, would eliminate use on the range altogether.

Regulating how robocowboys interact with human cowboys is not all that different from regulating how factory workers interact with industrial robots. One simply must identify what kinds of human behaviors are risky and then prohibit them or require the use of mitigating equipment.

Regulating the behavior of robocowboys through code imposes costs only to the extent that the regulatory requirements exceed what a good robotic cowboy designer would do anyway. A good designer is not going to design a robot that is likely to collide with the herd, a stray, another robot cowboy, or a human cowboy. Such collisions would damage the robot and be unacceptable to its users. So the relevant question for this regulatory strategy is whether the regulation needs to push beyond what is already good practice.

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270. *See supra* notes 212–29 and accompanying text (discussing OSHA guidelines on risk-mitigating measures for industrial robots).

271. *See* Exec. Order No. 12291, 46 Fed. Reg. 13193 (Feb. 17, 1981) (requiring federal agencies to conduct cost-benefit analysis).

The second source of cost depends upon the burdensomeness of compliance requirements procedurally. Requiring presale certification by a government agency is very expensive because it delays marketing and therefore the receipt of revenues and because it puts the agency in a position to nitpick design and to go beyond true performance regulation. It also imposes costs of testing meeting government standards. Record-keeping requirements do the same thing, to the extent that they require more than the designing entity would do anyway.

Sticking to performance standards, compliance with which the designer and vendor could self-certify, minimizes the basic cost of compliance. This approach could be backed up by heavy penalties if a vendor or designer is found to have mis-certified a robot and possible recalls, as this author has suggested for regulation of small drones.[272]

D. Patents: Incentives or Barriers?

The history and present application of the patent system presents a scattered approach to innovation policy. On the one hand, patents exist as an artificial property right in order to provide an incentive to inventors, protecting them from the free ride that pirates might otherwise get by imitating their inventions. On the other hand, patents are monopolies, and they inevitably restrain free competition and the innovation that can result from it. The Patents and Copyrights clause of the United States Constitution emerged from the history of the English Crown giving "patents" to favored merchants and industrialists, regardless of whether they had done anything innovative.[273]

The patent statute imposes novelty and utility requirements on applicants for patents, requiring them to shoulder the burden of proof that their invention constitutes something new, not already known to the "prior art," and that their invention is useful. Part of the novelty requirement is that the invention not be obvious to one with ordinary skill in the art.[274]

Applicants are barred from obtaining a patent if they have used the invention for too long without seeking one.[275] Patents, no matter how carefully granted to give monopolies only to true inventors, nevertheless have a blocking effect on other inventors. The Google patent claims, among other things, "a package securing subsystem attached to the autonomous road ve-

272. *See* Perritt & Plawinsky, *supra* note 240, at 26.

273. See *In re* Bilski, 545 F.3d 943, 976, 986 (Fed. Cir. 2008) (Newman, J., dissenting)((reviewing history of English patent systems)

274. *See* Agrichem, Inc. v. Loveland Indus., Inc., 843 F. Supp. 520, 530 (D. Minn. 1994) (holding patent for feedlot grain moisturizing system invalid for obviousness).

275. 35 U.S.C. § 102(a)(1) (2020) (disqualifying invention from patentability if "in public use, on sale, or otherwise available to the public").

hicle and comprising at least one securable compartment, each securable compartment operative to secure at least one package therein."[276] This orientation toward package delivery makes it obvious that the Google patent might have the effect of blocking innovation by Amazon, which obviously is interested in package delivery.[277]

E. Standardization

As Part III(A)(4) concludes, some form of standardization is necessary to realize the benefits of already available technologies for identifying individual cattle. Governmental intervention to establish such standards is not necessary, given the structure of the industry. The literature on standard-setting suggests that private entities in competitive markets are likely to have difficulty agreeing on and enforcing compliance with standards. This is because, most fundamentally, standards take one aspect of competition out of the equation for enterprises, and the literature on cartels uniformly concludes that individual firms always have an incentive to "cheat" on the agreed-upon limitation on supply, whether that be a price, a quantitative limit on production, or adherence to a technical standard.[278] Moreover, competition law places limits on collaborative efforts among competitors to agree on standards.[279]

But the structure of the beef industry is highly competitive only in its two upstream sectors—cow-calf operations and feedlots. The downstream beef packers segment is highly concentrated. The beef packers have an interest in standardizing cattle identification techniques so that they can associate their products with particular types of cattle raised in circumstances they specify.

The big three beef packers thus are likely agents for setting standards that the more competitive parts of the industry will honor. They have the power to enforce standards compliance by contracting only with those suppliers that demonstrate standards adherence. Even if competitive reasons cause each of the three to establish its own standard, three different standards addressing the same issue do not represent an unmanageable number

276. U.S. Patent No. 9,256,852 Claim 1.

277. *See* Steve Dent, *Amazon Acquires Self-Driving Startup Zoox*, ENGADGET (June 26, 2020), https://www.engadget.com/amazon-self-driving-acquires-zoox-090509371.html.

278. JTC Petroleum Co. v. Piasa Motor Fuels, Inc., 190 F.3d 775, 777–79 (7th Cir. 1999) (Posner, J.) (analyzing tendency of alleged cartel to collapse because of cheating by members).

279. *See* Allied Tube & Conduit Corp. v. Indian Head, Inc., 486 U.S. 492 (1988); Kurt J. Lindower, Case Note, Noerr-Pennington *Antitrust Immunity and Private Standard-Setting:* Allied Tube & Conduit Corp. v. Indian Head, Inc., 108 S. Ct. 1931 (1988), 58 U. CIN. L. REV. 341 (1989) (reviewing background and rationale for *Indian Head* decision).

for producers and consumers. Also, there is no apparent competitive advantage for any of the three to prefer its own standard, as opposed to a jointly adopted standard.

The government—the Department of Agriculture is the logical entity for doing so—can encourage standards adoption, but it should leave the content of the standards entirely up to industry groups.[280] When the government sets the standard itself, the resulting standard almost always lags behind the state of technology and opens the door to aided anticompetition-inspired political intervention with regard to standards modification and enforcement.

V. HOW WILL OTHER FORCES SHAPE THE ROLE OF ROBOTS ON THE RANGE?

Technology is not the only disruptive force for the cattle industry. Activism may matter as much as automation. Changing dietary habits, growing concern about environmental degradation and climate change, and growing sensitivity to animal rights all target the beef industry. Social and political pressure to eat less beef and to grow beef in different ways will influence methods of beef production and levels of demand for the product. In addition, economics always matters. Whatever robocowboys can do, it is not clear that they can do it as cheaply as human cowboys.

A. Cultural and Political Forces

The social movements related to agriculture will have only indirect influence on the design or introduction of robots into the beef industry. The focus of these movements is not automation and robotics. Whether the social forces will become regulatory requirements is uncertain. Only concerns about animal welfare and environmental protection are likely to result in new laws; both types of concerns have a significant history of being expressed in law. Public health concerns and other reasons for a move away from meat and toward vegetable diets are likely to remain but to have only limited influence on law. The following sections consider how such legal initiatives might impact the cattle industry.

280. *See* Walter Mattli & Tim Büthe, *Global Private Governance: Lessons from a National Model of Setting Standards in Accountings*, 68 L. & CONTEMP. PROBS. 225, 230–31 (2005) (enumerating reasons why government agencies delegate standard setting authority to private entities); *see generally* Lawrence A. Cunningham, *Private Standards in Public Law: Copyright, Lawmaking and the Case of Accounting*, 104 MICH. L. REV. 291 (2005) (critically analyzing instances in which government regulation mandates compliance with private standards).

In addition, of course, the usual anti-technology voices will claim that more robots will cost jobs and lead to human misery. They have, after all, been making the same arguments with respect to each new technology for 200 years.

1. Nutrition

Public concern with the adverse health effects of poor diets has been growing. Dietary improvement was not an unknown subject in the nineteenth century, but concern has greatly intensified in the last decades of the twentieth century and in the twenty-first century. Improved nutrition science has made it possible to understand the differential effects of eating different kinds of foods, sedentary lifestyles replacing hard manual work on the farm and in the factory have worsened physical fitness, and growing obesity have alarmed public health commentators. It is not uncommon for them and the general press and media to refer to the situation as a "crisis."

Many of the proposals for improved nutrition emphasize eating less red meat and animal fats.[281] During the same time period, consumer tastes have shifted away from beef toward poultry, pork, and seafood.[282] It is likely that the campaign for healthier diets will continue, and that this rhetoric, combined with food sciences improvements in "meatless hamburgers" and other simulated beef products, will continue to exercise a restraining influence on consumer demand for beef.

The vegetarian movement is growing, with major fast food operations and grocery suppliers introducing vegetarian beef substitutes and many opinion leaders on the political left, such as the Golden Globes international entertainment press association trumpeting its vegetarian awards dinner.[283] These popular anti-beef movements will intensify other phenomena that have caused the U.S. demand for beef to decline relative to other types of meat, especially chicken, since the early 1970s.[284]

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281. *Eating Less Red Meat, More Plant Protein and Dairy Can Improve Your Heart Health, Healthline*, HEALTHLINE, https://www.healthline.com/health-news/eating-more-plant-protein-and-dairy-products-may-improve-heart-health#:~:text=Two%20new%20studies%20are%20promoting,die%20of%20coronary%20heart%20disease (last visited Nov. 1, 2020).

282. One cannot be sure that the shift in consumer tastes is attributable mainly to calls by experts for better nutrition; it may be a result of simple shifts in consumer tastes, much as the first part of the Industrial Revolution was occasioned by consumer shifts toward beef. *See* Perritt, *Rise and Fall*, *supra* note 1, at 372–73.

283. *See* Dorany Pineda, *The Golden Globes are going vegan this year — even the stars' off-camera buffet*, LOS ANGELES TIMES, (Jan. 2, 2020), https://www.latimes.com/entertainment-arts/movies/story/2020-01-02/golden-globes-vegan-menu#:~:text=The%2077th%20annual%20Golden%20Globe,awards%20show%20of%20the%20season.

284. *See A Century of Meat*, N.Y. TIMES (Mar. 15, 2011), https://archive.nytimes.com/www.nytimes.com/imagepages/2011/03/15/science/15food_graphic.html?ref=science (show-

Slowing demand for beef will affect robotics on the range mainly by decreasing the amount of internally generated investment capital available to major beef producers to invest in robots. It also will decrease the willingness of outside investors to invest in robot projects to the extent that the rate of return from beef husbandry is adversely affected.

2. Environmental Concerns and the Green New Deal

Environmental concerns long have shaped the beef industry. Indeed, the first wave of creative destruction was occasioned in part by the antagonism of residents of towns and cities to having slaughterhouses in their neighborhoods and cattle drives through their streets.[285] The modern-day environmental movement, generally viewed as having been triggered by Rachel Carson's book *Silent Spring*,[286] has focused environmental protection efforts on agriculture, including the cattle industry. Runoff from feedlots as a source of water pollution has been a concern since the earliest days of the EPA, and environmental activists insist that feedlot control should be strengthened,[287] with accompanying limitations on where feedlots can be placed. Odors and noise from feedlots animate local zoning bodies to exclude them from areas close to dense populations.[288] As the population increases and as residential areas penetrate further into what had been rural territory, these pressures are increasing, ratcheting up the cost of land and the cost of environmental controls for feedlot operators. Indeed, three 2020 Democratic presidential candidates favored federal legislation to limit feed-

ing consumption of different kinds of meat for twentieth century; beef pounds per year rose by about 100% until the mid-1970s and then declined 1/3 to 2008).

285. *See* Perritt, *Rise and Fall*, *supra* note 1, at 391 n.133.

286. RACHEL CARSON, SILENT SPRING (1962); *see The Story of Silent Spring*, NAT'L RESOURCES DEF. COUNCIL (Aug. 13, 2015), https://www.nrdc.org/stories/story-silent-spring (discussing influence of *Silent Spring*).

287. *See* Concerned Area Residents for the Env't v. Southview Farm, 34 F.3d 114, 118–19 (2d Cir. 1994) (reversing district court and holding that feedlot was point source under Clean Water Act); EPA, GUIDE MANUAL ON NPDES REGULATIONS FOR CONCENTRATED ANIMAL FEEDING OPERATIONS (1995) (summarizing statutory and regulatory requirements under Clean Water Act for cattle feedlots).

288. *See* Coyote Flats, L.L.C. v. Sanborn Cty. Comm'n, 596 N.W.2d 347, 356–57 (S.D. 1999) (reversing circuit court and upholding denial of permit to construct feedlot); Altenburg v. Bd. of Supervisors, 615 N.W.2d 874, 877, 881 (Minn. Ct. App. 2000) (upholding ordinance restricting feedlots); Greg Henderson, *Missouri Feedlot Sued by Neighbors*, DROVERS (July 31, 2019, 8:27 AM), https://www.drovers.com/article/missouri-feedlot-sued-neighbors? (reporting litigation by neighbors against feedlot that sought permit to increase capacity from 900 head to 6999).

lots,[289] and proponents of the Green New Deal propose to restructure beef agriculture.[290]

Air pollution also is a concern, greatly intensified by the campaign against global warming. Some forty percent or so of greenhouse gases originate on farms and feedlots, potent sources of methane from cattle digestion.[291] These methane sources have been largely unregulated under the Clean Air Act because of the difficulty in addressing diffuse sources of air pollution as contrasted with point sources,[292] and because of the power of the agricultural lobby.[293]

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289. *See* Tom Philpott, *Cory Booker Just Went All-In Against Factory Farming and the Meat Industry*, MOTHER JONES (Dec. 16, 2019), https://www.motherjones.com/food/2019/12/cory-booker-just-went-all-in-against-factory-farming-and-the-meat-industry/ (describing presidential candidate Cory Jones' proposal for federal legislation to prohibit new feedlots, prohibit expansion of existing feedlots, and subsidize transition to "agriculture activities such as raising pasture-based livestock, growing specialty crops, or organic commodity production"; reporting that Senators Sanders and Warren support antitrust action against meat producers).

290. Katia Dmitrieva, *The Green New Deal Progressives Really Are Coming for Your Beef*, BLOOMBERG, (Mar. 13, 2019), https://www.bloomberg.com/news/articles/2019-03-13/the-green-new-deal-progressives-really-are-coming-for-your-beef.

291. Georgina Austin, *Agriculture Eyed as Culprit in Global Methane Emissions Spike*, INSIDE CLIMATE NEWS (Dec. 16, 2016), https://insideclimatenews.org/news/14122016/agriculture-methane-emissions-climate-change ("Climate gains from a leveling off of carbon dioxide emissions are offset by a spike in methane, bringing new scrutiny to the livestock industry."); Juliette Majot & Devlin Kuyek, *Big Meat and Big Dairy's Climate Emissions Put Exxon Mobil to Shame*, GUARDIAN (Nov. 7, 2017, 9:44 AM), https://www.theguardian.com/commentisfree/2017/nov/07/big-meat-big-dairy-carbon-emmissions-exxon-mobil (alleging that "three meat companies—JBS, Cargill and Tyson—are estimated to have emitted more greenhouse gases last year than all of France and nearly as much as some of the biggest oil companies like Exxon, BP and Shell").

292. *See* C. Gilmore & G. Riedel, *Biogeochemistry of Trace Metals and Mettaloids*, *in* ENCYCLOPEDIA OF INLAND WATERSPOINT SOURCE (2009), *reprinted at Diffuse Source*, SCIENCE DIRECT, https://www.sciencedirect.com/topics/earth-and-planetary-sciences/diffuse-source (observing that diffuse sources of pollution are more difficult to control than point sources).

293. *See* Dirck Steimel, *Keeping up the Pressure on EPA*, IOWA FARM BUREAU (July 15, 2019), https://www.iowafarmbureau.com/Article/Keeping-up-the-pressure-on-EPA (referring to campaign to get EPA to increase ethanol mandates); *see* Nancy Fink Huehnergarth, *Big Agriculture Bullies and Lobbies to Keep Americans in the Dark*, FORBES (May 5, 2016, 11:05 AM), https://www.forbes.com/sites/nancyhuehnergarth/2016/05/05/big-ag-bullies-and-lobbies-to-keep-americans-in-the-dark/#304ef676502c (criticizing power of farm lobby to limited public access to information about animal rights and competition); Daniel W. Drezner, *The Power of the Farm Lobby*, FOREIGN POLICY (July 26, 2007, 3:20 PM), https://foreignpolicy.com/2007/07/26/the-power-of-the-farm-lobby/ (describing political power of farm lobby, in general, and with respect to farm subsidies).

The law already regulates point sources of water pollution at feedlots.[294] Addressing other types of water and air pollution from cow-calf operations and feedlots is more difficult, from both a technical and political standpoint. When environmental protection agencies regulate point sources, they generally proceed by monitoring the amount of air or water pollution emitted from the source. Action is taken when the emission exceeds some prescribed maximum.[295]

That approach is not possible on non-point sources. It is difficult to calculate the amount of a particular pollutant in the runoff from a thousand-acre farm. It is even more difficult to calculate emissions of methane in the atmosphere near the same thousand-acre farm, or even a more concentrated feedlot. Shifting winds, changing density altitude, and varying amounts of sunlight all can affect methane levels.

Writing a regulation that could survive judicial challenge while resolving these metering uncertainties would be daunting.

Environmental regulators could seek to regulate greenhouse gases coming from cattle operations indirectly, by prescribing feeding practices. The science of low-methane cattle husbandry is in its infancy, however, and the quality of cause-and-effect data is unlikely to be mature enough to support regulatory initiatives for some time.

[296] The power of agricultural interest groups is the best explanation for the relatively light touch of EPA, OSHA, and USDA on safety and health matters on farms and closely associated agricultural facilities like feedlots.

Intensification of efforts to mitigate global warming is increasing pressure for regulating methane emissions from cattle.[297] Some reduction can be obtained by changing cattle diets.[298] Otherwise the campaign against me-

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294. *See National Pollutant Discharge Elimination System, Animal Feeding Operations*, U.S. ENVTL. PROTECTION AGENCY, https://www.epa.gov/npdes/animal-feeding-operations-afos (last visited Nov. 1, 2020).

295. See Nat'l Pork Producers Council v. U.S.E.P.A., 635 F.3d 738, 743 (5th Cir. 2011) (describing point-source regulation; invalidating EPA regulations for feedlots).

296. See Payne v. Fed. Land Bank of Columbia, 711 F. Supp. 851, 859 (W.D. N.C. 1989) (referring to "the farm lobby, a politically potent group if ever there was one," in discussing legislative history of statute governing farmland foreclosures.), vacated on other grounds, 916 F.2d 179 (4th Cir. 1990).

297. See Geoff Watts, *The Cows that Could Help Fight Climate Change*, BBC FUTURE, (Aug. 6, 2019), https://www.bbc.com/future/article/20190806-how-vaccines-could-fix-our-problem-with-cow-emissions.

298. *See Cargill Announces Commitment to Reduce Greenhouse Gas Emissions Across Its North American Beef Supply Chain*, CARGILL (July 24, 2019), https://www.cargill.com/2019/cargill-announces-commitment-to-reduce-greenhouse-gas-emissions ("Over the next three years, Cargill and TNC will work hand-in-hand with farmers and ranchers to demonstrate how grazing management planning and adaptive management improves sustainability outcomes related to soil, carbon storage, vegetation, wildlife habitat, water and other ecological parameters.").

thane is likely to be translated into louder calls for people to eat less beef, resulting in less cattle production, if they are effective in changing behavior.[299]

An anti-beef campaign has drawn the support of a number of celebrities,[300] though its scientific basis is questionable.[301]

3. *Animal Rights*

The animal rights movement grows out of the centuries-old concern about cruelty to animals.[302] In its recent form, it has resulted in the virtual eradication of the fur industry.[303] Animal welfare regulation in the beef industry has a long pedigree,[304] originating in state laws and Interstate Commerce Commission regulations before the turn of the twentieth century.[305]

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299. *See* Rachel Nuwer, *Raising Beef Uses Ten Times More Resources Than Poultry, Dairy, Eggs or Pork*, SMITHSONIAN MAG. (July 21, 2014), https://www.smithsonianmag.com/science-nature/beef-uses-ten-times-more-resources-poultry-dairy-eggs-pork-180952103/ (claiming that "ceasing to eat meat altogether may be the best choice for the planet"; making arguments that beef production is an inefficient use of resources and a major source of greenhouse gasses).

300. Brandon Blackburn-Dwyer, *Leonardo DiCaprio Joins with RSS Anti-Beef Movement*, GLOBAL CITIZEN (June 23, 2016), https://www.globalcitizen.org/en/content/leonardo-dicaprio-anti-beef/ (reporting on a number of public figures joining the anti-beef movement to "stop climate change"); Oliver Milman & Stuart Leavenworth, *China's Plan to Cut Meat Consumption by 50% Cheered by Climate Campaigners*, GUARDIAN (June 20, 2016, 4:08 PM), https://www.theguardian.com/world/2016/jun/20/chinas-meat-consumption-climate-change (describing new Chinese government guidelines).

301. *See* Erin Biba, *Can Vegetarians Save the Planet? Why Campaigns to Ban Meat Send the Wrong Message on Climate Change*, NBC NEWS THINK (Aug. 6, 2018, 10:34 AM), https://www.nbcnews.com/think/opinion/can-vegetarians-save-planet-why-campaigns-ban-meat-send-wrong-ncna896811 (exposing flaws in anti-meat campaign).

302. *See History*, AM. HUMANE, www.americanhumane.org/about-us/history (last visited July 17, 2020) (reporting that American Humane Society resulted from 1877 merger of several organizations concerned with treatment of farm animals).

303. John F. Burns, *Fur Industry Shrinking with No End in Sight*, N.Y. TIMES, Feb. 26, 1991, at D1 (reporting decline of industry, due in large part, to international coalition of animal rights advocates).

304. Humane Methods of Slaughter Act, Pub. L. 85–765, § 2, 72 Stat. 862 (1958) (codified as amended at 7 U.S.C. §§ 1901–1907) (enacted in 1958); *see* Nat'l Agric. Library, *Humane Methods of Slaughter Act*, USDA, https://www.nal.usda.gov/awic/humane-methods-slaughter-act (last visited July 17, 2020) (providing links to statutes and regulations).

305. *See* ANIMAL WELFARE INSTITUTE, LEGAL PROTECTIONS FOR FARM ANIMALS DURING TRANSPORT (no date), https://awionline.org/sites/default/files/uploads/legacy-uploads/documents/FA-LegalProtectionsDuringTransport-081910-1282577406-document-23621.pdf (last visited July 17, 2020) (explaining Twenty-Eight Hour Law regulating transport of cattle in railroad cars and providing text of law).

Activists regularly target meat processing as a source of mistreatment of animals.[306] The movement has changed the way that cattle are handled in transport, feedlots, and slaughterhouses,[307] and major producers consistently advertise their practices in assuring humane treatment of the cattle that pass through their operations.[308]

Additional regulatory requirements on the cattle industry to protect animal welfare are likely, beginning with a continuation of requirements for humane slaughter methods themselves, backed up by USDA inspections and enforcement[309] and additional regulatory requirements are likely with respect to treatment of animals on cow-calf operations and feedlots.[310] Density of cattle in enclosed spaces, the use of persuaders like electric cattle prods, and more aggressive cowboy techniques such as kicking or punching cattle are likely targets of regulators.[311]

Whatever the substantive requirements, regulators are almost certain to require training programs, record keeping with respect to which employees and contractors have been through the training programs, and some mechanism for recording incidents of animal abuse. Often, in other regulatory re-

306. "On today's . . . 'factory farms,' animals are crammed by the thousands into filthy, windowless sheds and stuffed into wire cages, metal crates, and other torturous devices. These animals will never raise their families, root around in the soil, build nests, or do anything that is natural and important to them. Most won't even feel the warmth of the sun on their backs or breathe fresh air until the day they're loaded onto trucks headed for slaughterhouses." *Factory Farming: Misery for Animals*, PETA, https://www.peta.org/issues/animals-used-for-food/factory-farming/ (last visited July 17, 2020) (concluding with call for vegan lifestyle).

307. *See* P. M. Seng & R. Laporte, *Animal Welfare: The Role and Perspectives of the Meat and Livestock Sector*, 24 REV. SCI. TECH. OFF. INT. EPIZ. 613 (2005), https://pdfs.semanticscholar.org/74b7/a3d7ccdc98b10cdd7fa93b55c3a20ae17b90.pdf (analyzing impact of animal rights concerns on beef industry).

308. *See* N. Am. Meat Inst., *Animal Welfare vs. Animal Rights*, ANIMALHANDLING.ORG, animalhandling.org (last visited July 17, 2020) (emphasizing industry's humane practices); *Animal Welfare*, CARGILL, https://www.cargill.com/news/animal-welfare (last visited July 17, 2020) ("[A]nimal welfare is one of our top priorities.").

309. *See* ANIMAL WELFARE INSTITUTE, HUMANE SLAUGHTER UPDATE: COMPARING STATE AND FEDERAL ENFORCEMENT OF HUMANE SLAUGHTER LAWS (2010), https://awionline.org/sites/default/files/publication/digital_download/humane_slaughter_update_pdf.pdf (providing overview of federal and state laws regulating slaughter of cattle).

310. *See Legal Protections for Animals on Farms,* ANIMAL WELFARE INST., https://awionline.org/sites/default/files/uploads/documents/FA-AWI-LegalProtections-AnimalsonFarms-110714.pdf (last visited Nov. 1, 2020) (providing overview of existing state and federal regulation and urging additional protections).

311. *Cow Transport and Slaughter*, PETA ANIMALS ARE NOT OURS, https://www.peta.org/issues/animals-used-for-food/factory-farming/cows/cow-transport-slaughter/ (last visited Nov. 1, 2020) (describing use of cattle prods, dragging, and beating).

gimes, these recordkeeping and reporting requirements are more onerous and expensive then substantive prohibitions.[312]

Concern with animal rights in the beef industry, however, suffers from an inherent contradiction: treating beeves well is one thing, but eventually killing them as a source for human food can be viewed—and is viewed by some—as the ultimate cruelty and deprivation of their rights. Despite the irony of promoting kindness to animals that are destined to be slaughtered within a matter of a few weeks or months, human society long has had sympathy for domestic animals, including cattle, as sentient beings. So the animal rights movement is necessarily, at its heart, an anti-beef movement. It combines with the environmental and dietary forces to limit the demand for beef, and therefore the level of production—at least that is its purpose.

4. *Effect on Robocowboys*

Feedlots have grown relative to open ranges for finishing cattle for two reasons. First, land has become more expensive, leading to smaller acreages for cattle raising. Second, feedlots permit cattle feed to be calibrated much more finely, based on the physical characteristics and health of particular groups of cattle.

Environmental and nutritional movements may change this trend. Nutritional preferences for grass-fed beef may have some effect, at the margins, on how cattle are finished, but not nearly enough land is available for grass feeding to amount to a significant fraction of total production.[313] Environmental activism, whether based on NIMBY[314] or genuine environmental concerns, is already making it difficult to expand feedlots or to find sites for new ones.

Both forces will slow the move from the range to the feedlot and may actually reverse historical trends and begin to move some cattle from the feedlot back to the range.

The effect on the demand for robots will be to increase the demand for range robots and to decrease the demand for feedlot robots.

On the other hand, growing population density and land-use politics inexorably diminish the use of open range for breeding and finishing cattle. In

312. *See Bilingual Non-Ambulatory Cattle Management Training Program with Certification Offered*, BEEF MAG., https://www.beefmagazine.com/people/0425-bilingual-training-program (last visited Nov. 1, 2020).

313. See Jonathan Carey, *Is Grass-Fed Cattle a Sustainable Farming Practice?*, SENTIENT MEDIA, (Aug. 7, 2018), https://sentientmedia.org/is-grass-fed-cattle-a-sustainable-farming-practice/ (summarizing Harvard study concluding that available land is insufficient to support grass-fed cattle).

314. Not in My Back Yard. *See generally NIMBY*, WIKIPEDIA, https://en.wikipedia.org/wiki/NIMBY (last visited July 7, 2020).

other words, the long-term tendency will be to fold cow-calf operations into feedlots. Animal rights and organic-farming movements push in the other direction, of course, but the economics of confined cattle raising ultimately are as compelling as they are for confined chicken and pork raising.

Moreover, concerns about environmental pollution from cattle farming and finishing can be addressed more effectively for confined spaces like feedlots, as contrasted with open ranges. At the limit, a feedlot could be entirely enclosed, permitting emissions of methane to be captured, a goal unachievable on the open range. This would be enormously expensive, of course, and may never happen. Whether it happens depends on the balance of political forces; not on technology.

A feedlot is an operation that uses little land to feed large number of cattle.[315] So feedlots accommodate land scarcity. Opposing them are anti-feedlot forces and grass-fed cattle forces. The political forces may combine with land scarcity to produce a new intermediate beef production niche, in between feedlots and open range ranching. Such a niche already exists, to some extent, with small cow-calf operations.

B. Economics

Overcoming the challenges described Part III is feasible. The nature of the goals for image recognition, navigation, and guidance are similar in kind to those involved in designing safe self-driving automobiles and trucks. They are also similar in magnitude.

But technological feasibility does not predict reality; economics motivates behavior. Can robocowboys compete with human cowboys in the marketplace?

The potential for robocowboys is different in the three subindustries. In each, however, the price of a human cowboy limits the maximum price of a robocowboy. The maximum price at which a robocowboy can be sold (or rented) and the numbers that can be sold represent the entrepreneurial op-

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315. The Farm System Reform Act of 2019 imposes a moratorium on large feedlots. S. 3221, 116th Cong. §§ 101(3), 102 (2020) (defining "large concentrated animal feeding operation" as including, inter alia, animal feeding operations having at least 1,000 cattle; immediately prohibiting establishment or expansion; prohibiting operation after January 2040). The bill defines feedlot—"Animal Feeding Operation"—as a facility in which animals are "stabled or confined, and fed or maintained," where "crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility." *Id.* § 101(2). This does not include a lot or facility in which animals are confined which does sustain some vegetation or forage growth; the definition does not require the natural growth of vegetation be sufficient to feed all the animals confined there. So a small cow-calf operation with an extremely large herd of cattle would not be a feedlot under the definition so long as some grass grows on the property.

portunity. Even if there is a market for some robocowboys, it may not be big enough to attract the investment necessary to design and manufacture them.

1. *Elasticity of Substitution*

Economists would evaluate the likelihood of robocowboys replacing human cowboys in terms of the elasticity of substitution.[316] The elasticity of substitution is the proportional change in the relative amount of one factor used as compared with another, as a function of their relative productivities.[317] Productivity in this sense includes cost. Thus, a simple application of the concept evaluates changes in the relative demand for a human cowboy or a robot based on their relative prices, assuming each can do the same tasks with equal efficiency.

According to the U. S. Department of Labor's Bureau of Labor Statistics, the median annual pay in 2018 for "agricultural workers" was $24,620, and the category included 876,300 workers.[318]

If a robocowboy able to do the same work were priced below $24,620 each, at least some cowboys would be replaced by robocowboys. If a robocowboy could do twice the work in the same amount of time, it could be priced just under $49,294 each and find a market.

Cowboy labor is cheap. Spending ten times the wages of a human cowboy for a robot that can perform only *almost* as well as a human cowboy is not a good business decision. Unless, that is, it produces sufficient gains in productivity or safety or other values that make the investment worthwhile.[319] Even if it is worthwhile, the agricultural community is "sluggish" in embracing new technologies.[320]

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316. *See* Autor, *supra* note 5, at 7 (noting importance of elasticity of substitution in evaluating substitution effect of new technologies).

317. A.C. Pigou, *The Elasticity of Substitution*, 44 ECON. J. 232, 232 (1934) (defining [then] new concept).

318. BUREAU OF LABOR STATISTICS, OCCUPATIONAL OUTLOOK HANDBOOK: AGRICULTURAL WORKERS, https://www.bls.gov/ooh/farming-fishing-and-forestry/agricultural-workers.htm.

319. *See generally* Rachael Lallensack, *Five Roles Robots Will Play in the Future of Farming*, SMITHSONIAN MAG. (Sept. 30, 2019), https://www.smithsonianmag.com/innovation/five-roles-robots-will-play-future-farming-180973242/ (arguing that "aging workforce, shortage of low-cost labor, environmental hazards and climate change" will bring robots to the farm, especially fruit pickers, weed pullers, data collectors, drones, and farmer exoskeletons); Laurie Bedord, *Robots Take to the Fields in Indiana*, SUCCESSFUL FARMING (June 30, 2017) https://www.agriculture.com/news/technology/robots-take-to-the-fields-in-indiana (reporting on "agBOT Challenge" hosting a competition in which more than a dozen robots competed, seven planting corn, nine that weeded and fertilized crops); Laurie Bedord, *How Automation Will Transform Farming*, SUCCESSFUL FARMING (Nov. 29, 2017), https://www.agriculture.com/technology/robotics/how-automation-will-transform-farming; Nate Dorsey, *Top 5 Robotic Systems to Watch in Agriculture*, PRECISION AG. (Mar. 21, 2019),

Supply and demand pressures also matter. As this is being written, (just before the COVID-19 crisis) U.S. labor markets are tighter than they have been in decades.[321] Everyone, including ranches, feedlots, and trucking carriers have "help wanted" signs out. A significant part of the demand for industrial robots is the shortage of human workers.

From the perspective of a modern-day labor economist, journalist, urban millennial, or student of occupational specialties, being a cowboy is not a particularly desirable job: the pay is low, the work is dangerous and uncomfortable, and much of it is quite boring. Even as the business cycle softens labor markets, human cowboys may be difficult to recruit, especially if immigration from Mexico diminishes. Continued tightness in the supply of human cowboys will tend to intensify the demand for robocowboys to do the work that no one else is willing to do. On the other hand, the romance, the opportunity to work outdoors, and the independence that range workers enjoy will always appeal to some people.

Estimating the likely penetration of robocowboys requires considering each of the three subsectors separately.

2. Highways: Texas

Texas, the cattle-truck robot, has the most promising future. Agreement is widespread that self-driving trucks will dominate the highway transportation industry in due course.[322] The same economic and safety considerations that favor self-driving trucks in general favor self-driving cattle trucks. Tex-

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https://www.precisionag.com/in-field-technologies/top-5-robotic-systems-to-watch-in-agriculture/ (reviewing vineyard pruner and lettuce thinner by Vision Robotics in San Diego; lettuce thinner by Agmechtronix; RIPPA robot for weeding and pesticide application by the University of Sidney, Australia; weeding robot by Naio Technologies); Khasha Ghaffarzadeh, *Agricultural Robots and Drones 2018-2038: Technologies, Markets and Players*, IDTECHEX (last visited July 17, 2020), https://www.idtechex.com/en/research-report/agricultural-robots-and-drones-2018-2038-technologies-markets-and-players/578.

320. In more formal terms, the elasticity of substitution is lower in the cattle industry than in other industries.

321. *Job Market Remains Tight in 2019, as the Unemployment Rate Falls to Its Lowest Level Since 1969*, U.S. BUREAU OF LABOR STATISTICS, (Apr. 2020), https://www.bls.gov/opub/mlr/2020/article/job-market-remains-tight-in-2019-as-the-unemployment-rate-falls-to-its-lowest-level-since-1969.htm#:~:text=April%202020-,Job%20market%20remains%20tight%20in%202019%2C%20as%20the%20unemployment%20rate,the%20lowest%20rate%20since%201969.

322. *See Self-Driving Trucks: What's the Future for America's Truck Drivers*, REDWOOD, https://www.redwoodlogistics.com/self-driving-trucks-whats-the-future-for-americas-truck-drivers/#:~:text=Most%20experts%20agree%20that%20over,will%20slowly%20diminish%20over%20time (predicting gradual replacement of truck drivers with self-driving trucks) (last visited Aug. 23, 2020); *Robot Apocalypse Ahead? The Future of Self-Driving Trucks (and Drivers)*, NEXTEXIT LOGISTICS, https://nextexitlogistics.com/robot-apocalypse-ahead-the-future-of-self-driving-trucks-and-drivers/ (last visited Aug. 23, 2020).

as and his comrades are tireless, work all the time, and do not make trouble in the form of demanding improved pay or working conditions.[323]

Texas, however, may face potential barriers that do not discourage early adoption of self-driving trucks by the trucking industry in general. In the more heavily regulated and organized part of the industry, decisions on new product adoption are made by enterprises, often motivated to replace employees with the new robots. Reducing the need for human truck drivers is a powerful incentive for big truckers to embrace self-driving trucks.

But the agricultural part of truck transportation, beef hauling in particular, is dominated by independent owner-operators.[324] They have no incentive to replace their own labor with a machine; to do so would put them out of business. Moreover the downward price elasticity of supply[325] is low for owner-operators because, most observers agree, they do not accurately account for their total costs, often failing to account for depreciation of their truck tractor—their biggest capital asset.[326] That makes it likely that as self-driving truck tractors come on the market, owner-operators will underbid them in order to retain their share of the market. In other words, a two-tier arrangement is likely, one in which the larger trucking companies replace substantial numbers of their driver-employees with robot trucks, while the more fragmented part of the industry continues to use human drivers.

This result will be intensified by the greater technological challenges of designing self-driving trucks for the unpredictable routes and unimproved roads involved in linking cow-calf operations to feedlots and linking the smaller feedlots to beef packers.[327]

3. Feedlots: Montana

Montana may face an even brighter future than Texas. Feedlots present early opportunities for robocowboys. The top end of the feedlot sector is concentrated, and the state of the equipment market for this sector suggests that larger feedlot enterprises are interested in and willing to adopt new

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323. They do, however, malfunction and require maintenance. So it is not quite true to say that they "do not make trouble."

324. *Owner Operators*, CARGILL, https://www.cargill.com/transportation/cmls-owner-operators (last visited Nov. 1, 2020) (encouraging owner operators to "partner" with Cargill). Cargill is one of the largest corporate beef producers; *3 Things Every Trucker Should Know About Hauling Livestock*, ARROW TRUCK SALES, (Sept. 12, 2019), https://www.arrowtruck.com/blog/2019/09/12/3-things-every-trucker-know-hauling-livestock/ (explaining how independent truckers can succeed in paling livestock).

325. The tendency of truckers to exit the industry when compensation goes down.

326. *See* Michael T. Lyon, *ICC Regulation: The Economics of Motor Carriage*, 19 STAN. L. REV. 217, 223 (1966) (explaining why owner-operator truckers may price below total costs).

327. *See supra* Section III.A.4.a.

products and technologies.[328] In addition, as Section III.A.4.b explains, the engineering challenges of designing and building robots for feedlot tasks are far less daunting than building robots for cow-calf operations. It is no accident that Cargill advertises its robocowboy in the context of feedlot work.

4. The Range: Dakota

Dakota faces the most daunting future, but if he succeeds in finding a place on the range, he will be the most sophisticated robocowboy of the three. The cow-calf sector will be the slowest to embrace robocowboys. The engineering changes for designing a useful Dakota are significantly greater than those for designing a successful Texas or Montana, as section III.A.3 shows.

The fragmented structure of the industry also means that the vast majority of cow-calf operators lack the capital for cooperative research and development (R&D) and for aggressive experimentation with new technologies embedded in products. The same fragmentation makes this a difficult market to sell to. A salesperson must make more contacts to make a sale, and when she makes a sale, it is likely to be a small one.

Wages are low in the sector, and that reduces the economic advantages that any form of automation and substitution of robots for human labor can offer. The attractiveness of robots and the pace of automation might accelerate if prolonged labor shortages develop.[329] But as robocowboys push cowboys off of feedlots and make their labor available to other sectors, such as range work, the supply of human cowboys for range work will increase, blunting the attractiveness of robotic substitutes.

5. Scale

Regardless of the elasticity of substitution and labor market conditions, entrepreneurs aspiring to build and sell robocowboys must believe that the scale of the market is sufficient to justify the necessary investment in R&D. In 2007, some 750,000 cow-calf operations existed in the United States,

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328. "Cattle Feeding," *Cattle & Beef Sector at a Glance*, USDA, https://www.ers.usda.gov/topics/animal-products/cattle-beef/sector-at-a-glance/ (last visited Nov. 1, 2020) (describing concentration of feedlot industry).

329. Labor shortages exist now, at the peak of the business cycle, but they are almost certain to disappear as the boom morphs into a downturn. Immigration policy also could produce labor shortages, because so much of the bottom of the agricultural workforce comprises immigrants—legal and illegal. *See* Ramos et al., *supra* note 209, at 1 (noting importance of immigrant labor to cattle feedlot industry); Temporary Agricultural Employment of H-2A Foreign Workers in the Herding or Production of Livestock on the Range in the United States, 80 Fed. Reg. 62957, 62961 (Oct. 16, 2015) (codified at 20 C.F.R. Part 655) (summarizing history of foreign cattle ranch labor).

most of them small.[330] If one assumes that, on average, half of them had a hired hand, that would mean 375,000 cowboys, not accounting for feedlot employees. A ten percent market penetration would mean 37,500 robots, assuming that each robot replaces a cowboy. At $25,000 each,[331] that would generate nearly a billion dollars of revenue.[332] That is not an insubstantial amount. Assuming that engineers command compensation on the order of $100,000 annually, and that twenty-five percent of total revenue is available for R&D, a robocowboy enterprise could afford to put more than 2,000 engineers to work on its product.

In other words, it is plausible that the future for robocowboys may be bright enough to attract the requisite investment in R&D and product commercialization.[333] So hundreds of the best engineers may be willing to spend many thousands of hours to solve the technology problems. The business question then becomes whether that level of R&D investment is worth it.

Aggregate analysis suggests that scale is adequate. But that may not be true when one considers the need for specialization of robots: Dakota, Montana, and Texas together may attract a large market, but each of them faces a smaller specialized market. The more one narrows subject matter, the less it costs to develop a competent robot. A robocowboy that recognizes Hereford cattle, but not other breeds, would be considerably cheaper than one that can deal with the full range of cattle breeds. But the number of Hereford-only cow-calf operations and feedlots may provide an insufficient revenue stream to earn an adequate return on R&D investment for such a limited robot.

Section III.A.3 makes it clear that the challenges for the design of a robocowboy that could function effectively in a feedlot are much fewer than those for a robocowboy that could function effectively on a cow-calf ranch. Likewise, the same section makes it clear that the robot design challenges for cattle hauling operations are not much different from those for self-driving automobiles and trucks in general. It is likely that robocowboys will be designed and deployed in these two segments of the industry first, long before they are deployed on the range. That means that the scale for entrepreneurs is measured, not by the size of the entire industry, but only by the size of two of its segments.

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330. WILLIAM D. MCBRIDE & KENNETH MATHEWS, JR., U.S. DEP'T OF AGRIC., EIB-73, THE DIVERSE STRUCTURE AND ORGANIZATION OF U.S. BEEF COW-CALF FARMS (2011) (reporting 765,000 cow-calf operating in U.S. in 2007; 80% with fewer than fifty cows).

331. *See supra* note 303 (giving average wage of human cowboy).

332. $25,000 multiplied by 37,500 robots equals $937,500,000.

333. A more robust model also would consider profit margins, capitalize the stream of income generated, and apply return-on-investment requirements to compute the amount of capital that can be justified.

6. Marketing

Effective innovation requires far more than development of new technologies that perform useful tasks. It may be possible to build a prototype robocowboy that functions well in a laboratory environment created on a sample range, but that will have no effect on the beef industry unless someone offers the robot for sale and beef industry enterprises buy it in sufficient numbers to induce investment in its development and manufacture.

The connection between an engineer's prototype and a rancher's range comprises the marketing function in business administration.[334] Successful entrepreneurs are able to define the need that a product satisfies, assess its relative attractiveness economically in satisfying that need, measured against alternatives. That stage of marketing implicates pricing and detailed product design.

The industry structure will affect the pace at which new technologies diffuse through the beef industry. First movers are more likely to be found in the sectors with the highest concentration. Larger entities have more resources available in the aggregate for cooperative R&D with robot designers and to risk capital on innovative tools. In addition, higher concentration reduces marketing costs for robot suppliers; their sales forces need to contact fewer potential customers and the potential size of a purchase is greater when a sale is made.

An entrepreneur must identify the channels through which decision-makers can be persuaded to buy the product and the channels through which it will be delivered to them. That stage of marketing comprises the sales and order-fulfillment functions.

Successfully carrying out these marketing activities benefits from detailed knowledge of beef industry functions, the industry's needs for better methods, the identity of the decision-makers in the industry with respect to the purchase of capital equipment, and the sales communications they are likely to find persuasive. That means that established providers of farm equipment for the industry have an advantage in selling robocowboys. They may or may not elect to do so, however. Stories are legion about incumbent enterprises that shunned new technologies that eventually eclipsed them, because they were afraid of the adverse effect of the new technologies on existing product sales. Kodak's shunning of digital photography is a particularly dramatic example.[335]

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334. *See Subjects*, MIT, http://catalog.mit.edu/subjects/15/ (last visited July 17, 2020) (course descriptions for basic marketing courses in MBA and SB programs).

335. Chunka Mui, *How Kodak Failed*, FORBES, (Jan. 18, 2012) https://www.forbes.com/sites/chunkamui/212/01/18/how-kodak-failed/?sh=2c45ec136f27 (describing Kodak's descent into bankruptcy, beginning with turning its back on digital camera in 1975).

In understanding this process of diffusion of new technologies through marketing, one should not underestimate the retarding influence of inertia. Most people instinctively resist new ideas, particularly when embrace of the new ideas creates a sense of uncertainty and insecurity about long-established occupational pathways. Many ranchers and feedlot operators will say, “We’ve always done it this way,” or, “If it ain’t broke, don’t fix it.” Many farm equipment salesmen will silently be fearful of their inability to learn new technologies embedded in robots. Executives at firms will resist the disruption to present organization, recruitment, and management techniques necessarily occasioned by incorporating new technologies and new product concepts.

But robocowboys intended for use on cow-calf ranches and in cattle feedlots are not going to replace existing products sold by farm equipment manufacturers; they will mostly replace labor, and the incumbent equipment manufacturers have no vested interest in preserving the labor content of beef production.

Self-driving trucks, on the other hand, will replace trucks intended to be used with human drivers, so some cannibalization of existing product lines of truck manufacturers can be expected. That might lead to greater resistance to the introduction and widespread deployment of self-driving cattle trucks.

Despite the likelihood that existing farm equipment manufacturers will dominate the market for cattle industry robots, an important role exists for startup enterprises specializing in robot technology. These are the firms that show off the latest technologies and product capabilities at trade shows. As they demonstrate their superiority over existing methods—which takes a while, especially because the new technologies often are *not* superior at first—they will develop market share themselves or will be bought out by larger incumbents, who have more capital and established sales forces.

7. Conclusion

The three sectors of the cattle industry will experience significantly different levels of robot adoption. Texas and other self-driving cattle trucks will dominate the transportation of beef. Further automation in the beef packing sector will be less visible, however, because of the relatively high level of mechanization that already exists, including robots for many slaughtering and packing tasks. Further steps in this direction will be incremental rather than revolutionary.

Where it is difficult to program Texas to operate in unimproved areas and load from unpredictably designed cattle pens and ramps, the economics of Texas may induce a significant portion of the cow-calf operators to provide better, more predictable interfaces for self-driving cattle trucks. The long-term career prospects for Bennington are not great.

Montana also is likely to reduce job opportunities for Nash. Significantly, Cargill's Robot Cowboy is depicted as working in feedlots.[336] The confined spaces of feedlots, and the regularity of pathways make robot operations easier to design for feedlots than for farms and ranges.

Whether Kirby needs to be afraid that Dakota will take his job is an entirely different matter. Robot deniers should consider the computer code offered in the Appendix, which demonstrates that robots can be programmed to perform the tasks that human cowboys perform on the open range. But robot enthusiasts and those sure that robots will doom human work should realize how expensive it will be to design and build good robots for the range and to make them cost competitive with Kirby, who has finely honed motor skills and does not make much money.

Increasing land scarcity will ratchet up the cost of open-range cow calf operations.

VI. WHAT SHOULD POLICYMAKERS DO?

Dakota, Texas, and Montana face daunting economic challenges and more modest technological ones. The industries in which they work may shrink because of cultural and political campaigns against the beef that they produce. They also may face legal hurdles.

The technology and economic challenges are objective; they will be met by engineers, entrepreneurs, and marketing professionals. Public policy serves progress best in these areas by staying out of the way.

The cultural and political campaigns may or may not be rational, but they are reality. Policymakers will, for the most part, respond to them rather than shape them.

The size of the legal hurdles, however, is controllable by intelligent analysis. Law in a democratic society is the crystallization of informal norms, advocated by political actors. Political opposition to robocowboys could come from two quarters. The typical claim by opponents of new technology is that it will cost jobs. To the extent this claim resonates with a significant segment of the public, political actors will favor almost any kind of limitation on robocowboys, believing that they are thereby saving human cowboy jobs. Often, the shrillest opponents of technology as a job killer are not those who actually hold the jobs that might be threatened, but urban elites of the "progressive" stripe.

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336. *See Meet the Robot That's Making Cattle Herding Safer*, CARGILL, (Oct. 18, 2018), https://www.cargill.com/story/meet-the-cowboy-robot-thats-making-cattle-herding-safer.

The second source of opposition comprises business owners who fear that robot-equipped competitors will be more efficient than they are. They can best protect their existing market shares, they think, by ensuring the status quo against innovation.

Both favor any regulatory or legal initiative that discourages development of robocowboys.

These proposals are good examples of the fallacy of wanting the law to stay ahead of technology. It is far better when the law lags technology. In a well-functioning market economy, friendly to innovation, regulation emerges from actual, demonstrated, risks.

Law is often criticized for being behind technology.[337] That is not a weakness; it is a strength. The author has often written that the law *should* lag technology. For if law were to lead technology, innovation would be stifled. What would be legal would depend on guesses by lawmakers about the most promising directions of technological development. Those guesses are rarely correct. When law follows technology, it can fill in gaps and correct the directions of other societal forces that shape behavior: economics, societal pressure, and private lawsuits.

Here is how law should work. A new technology is developed. A few entrepreneurs build it into their business plans. In some cases, it will be successful and spread; in most cases it will not. New technologies that spread successfully will impact other economic players. The technologies will confront non-adopters with the necessity of utilizing new technology to remain economically viable.

New technology will probably cause accidents, injuring and killing some of its users and injuring the property and persons of bystanders. Widespread use of the technology will also have adverse effects on other intangible interests, such as privacy and intellectual property. Those suffering injury will seek compensation from those using the technology and try to get them to stop using it.

Most of these disputes will be resolved privately, without recourse to governmental institutions of any kind, but some of them will find their way to court. Lawyers will frame the disputes in terms of well-established rights, duties, privileges, powers, and liabilities. The courts will hear the cases, with lawyers on opposing sides presenting creative arguments as to how the law should be understood in light of new technology. Judicial decisions will result, carefully explaining where the new technology fits most appropriately within long-accepted legal principles.

Law professors, journalists, and interest groups will write about the judicial opinions and gradually, conflicting views will crystallize as to wheth-

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337. The author has made this argument before. *See* Henry H. Perritt, Jr., *Who Pays When Drones Crash?*, 2017 UCLA J.L. & TECH. 1, 79 (2017).

er the judge-interpreted law is correct for channeling the technology's benefits and costs. Eventually, if the matter has sufficient political traction, someone will propose a bill in a city council, state legislature, or the United States Congress to change the standards being applied by the courts. Alternatively, an administrative agency will issue a notice of proposed rulemaking and a debate over codification of legal principles will begin.

This is a protracted, complex, and unpredictable process, and that may make it seem undesirable. But it is beneficial because the resulting adversarial, deliberative interplay produces good law. It is the only way to test legal ideas thoroughly and assess their fit with the actual costs and benefits of technology as it is deployed in a market economy.[338]

That is how the Internet has evolved. The Clinton Administration wisely deflected early calls for a comprehensive scheme to regulate the Internet, which if followed, would have applied legacy telephone regulation to it.[339]

One of the goals of this article is to show that calls for regulating robots, or machine learning, or AI, in general, are not much more useful than would be calls for regulating human behavior, in general. The applications of these new computer science technologies are simply too diverse to be regulated usefully unless the law understands them and particularizes measures to reduce the risks associated with them.

No new regulatory regime is needed for robocowboys; OSHA already has one. The existing OSHA guidelines, if translated into performance standards for robocowboys, should pose tolerable costs for designers and manufacturers. On the other hand, thoughtless paranoia about robots taking jobs resulting in robot taxes or other regulations indirectly intended to dissuade the success of robots would be harmful to continued productivity in the cattle industry.

The European approach of imposing "conformity approvals" results in a ban on deployment of new technologies, meaning that no data is developed on actual risks.

Analysis of the technology of robots and its application to the cattle-raising industry shows three truths about the future of robotics, machine learning, and this kind of AI. First, almost anything is possible, given increases in computing power and advances in the techniques of machine learning. Dakota, Texas, and Montana all could become pretty good cowboys. Second, however, the effort required to build good intelligent systems is very industry-specific; scanning 10,000 images of cowboys chasing herds of cattle is not going to do much good if one is trying to build a robot to fill

338. *Id.* at 79–80.

339. The author was a member of the Clinton Administration transition team, working on telecommunications policy and worked closely with Administration policymakers in the White House as they determined the Administration's policy toward the Internet.

grocery orders. Third, building good intelligent systems will continue to be very expensive. Outside the industrial robot industry, results obtainable from robots have not been so startling that decision makers are willing to buy or rent robots in large numbers.

These conclusions about technology and economics are relevant to law, because they say that the near hysteria that motivates the call for robots to be regulated generally before they take over the world is misplaced and based more on fantasy than reality.

A thoughtful recent article in the Georgetown Law Journal concludes that

> [c]ontrary to popular perceptions, machine learning will not lead to a runaway government, as a series of technical limitations preclude a future in which complete regulatory or adjudicatory power can be ceded to autonomous algorithms over which humans exert little control. When used thoughtfully, these machine-learning applications should not offend the core legal foundations of the regulatory state.[340]

The authors considered the opacity argument and concluded that transparency in administrative decision making would be served by disclosing the role of machine learning in agencies. But, the authors continued,

> [t]o say that machine learning has a black-box nature does not mean it is completely impenetrable to human examination. Rather, . . . it means that machine-learning methods for transforming inputs to outputs are not as intuitively interpretable as more traditional forms of data analysis. This is different than saying that no one can know at all how algorithms generate their predictions, which we would agree would undermine the transparency of any technique underlying administrative action. Machine learning can be understood and explained. Analysts can, and do, possess full knowledge of algorithms' inner workings, and they can mathematically explain how these algorithms optimize their objective functions. What they lack is simply an interpretive ability to describe this optimization in conventional, intuitive terms. They cannot say that a machine-learning analysis shows that X causes Y, and therefore a government agency aiming to reduce Y needs to regulate X.[341]

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340. Cary Coglianese & David Lehr, *Regulating by Robot: Administrative Decision Making in the Machine-Learning Era*, 105 GEO. L.J. 1147, 1154 (2017).
341. *Id.* at 1206–07.

APPENDIX

The master loop is shown below, in Figure 1. The loop continues until alert is false, signifying that the straggler has been returned to the herd. As long as alert is true, signifying that the straggler is still separated from the herd, the loop updates the herd position (line 7), updates the value of alert (line 9), updates the robot's position (line 11), updates the straggler position (line 13), chooses one of a plurality of robots to chase the straggler (line 15), increments the value of time by the time increment (line 17), and returns the new values of everything.

Figure 1

```
1   # roboCowboyMasterLoop
2
3   include math
4
5   while alert == true:
6
7       herdPos = updateHerdPos(deltaT, herdLat, herdLon, herdHdg, herdSpeed)
8
9       alert
10
11      robotPos = updateRobotPos (robotNumber,deltaT, robotLat, RobotLon, robotHdg, robotSpeed))
12
13      stragglerPos = alert * updateStragglerPos(deltaT, stragglerLat, stragglerLon, stragglerHdg, stragglerSpeed)
14
15      Choose
16
17      t = t + deltaT
18
19  return (herdPos, robotPos, stragglerPos, alert)
```

Figure 2 shows the code for the function that models the robot's chasing the straggler to force it back into the herd—the basic herding behavior of the robot. The function is active only as long as alert is true (line 5), signifying that a straggler has separated from the herd. Lines 7 and 8 compute the heading from the robot to the straggler and the distance from the robot to the straggler. *findVector* is a separate function that returns a Python list comprising heading and distance between two points. If the robot is outside the flight zone of the straggler (line 10) the robot closes on the straggler at its maximum speed (line 11). Otherwise, it approaches at reduced speed (line 12). The function for reducing speed as the robot gets closer could be expressed as a variety of decay functions.

Once the robot gets inside the flight zone (line 14) it changes its heading to match the heading from the straggler to the herd and adjusts its speed to match that of the straggler, as the straggler turns toward the herd. Once the straggler has returned to the herd, making alert false, the function returns (line 18).

The other functions, *findVector* and *herdingSpeed* are not shown in detail, in the interest of streamlining the example. Also not shown in detail is the *stragglerFlight* function, which models the behavior of the straggler once the herding robot gets within its flight zone.

Figure 2

```
#chaseAStraggler

import math

if alert == True:

    robotHdg = findVector(stragglerLat, stragglerLon, robotLat robotLon)[0]
    robotDist = findVector(stragglerLat, stragglerLon, robotLat robotLon)[1]

    if robotDist > flightZone:
        robotSpeed = robotMaxSpeed
    else robotSpeed = (1/robotDistance) * robotMaxSpeed

    if robotDist < flightZone:
        robotHdg = findVector(stragglerLat, stragglerLon, herdLat, herdLon)[0]
        robotSpeed = robot herdingSpeed

else return
```