스마트 가축질병 방역 강화 방안 연구

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목 차

국외훈련개요

1. 훈련국 : 영국

2. 훈련기관명 : 켄트대학교 (University of Kent)

3. 훈련분야 : 방역정책

4. 훈련기간 : 2022. 8. 29. - 2024. 9. 6.

훈련기관 소개

It was first established as the University of Kent at Canterbury in 1965 with a royal charter. As it grew, colleges and buildings were added colleges and buildings, including the Tonbridge campus in 1982 and the Medway campus in 2001.

The Canterbury campus consists of six colleges, named after famous British figures: Eliot College, Rutherford College, Keynes College, Darwin College, Woolf College and Turing College. The University of Kent is organised into six faculties (Arts and Humanities, Natural Sciences, Computing, Engineering and Mathematics, Business, Humanities and Social Sciences, Law, and Social and Social Justice) and 21 departments. In addition to the UK, Kent has campuses in France, Belgium, Italy and other European countries. It is often referred to as the UK's European University due to its high proportion of students from outside the UK.

Major departments include film, art & music, social policy, sports science, electrical & electronic engineering, accounting & finance, and more than 20,000 students from 158 countries. International social policy is taught through the School of Social Study, Sociology, Social Research, and focuses on welfare policy. It studies a broad range of social policies, including labour policy, women's policy, and poverty policy. The programme requires a total of 300 credits for graduation, including 240 credits through coursework and 60 credits through a dissertation.

훈련결과보고서 국문 요약서

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<tr><td>내용요약</td><td colspan="4">1. 서론: 가축 전염병의 세계적 영향

가축 전염병은 단순히 축산업에만 국한된 문제가 아니라 국가 경제, 국제 무역, 식량 안보, 그리고 환경 보호에까지 폭넓게 영향을 미치는 중대한 문제이다. 예를 들어, 2018년부터 중국을 강타한 아프리카 돼지열병(ASF)은 전 세계 돼지고기 시장에 심각한 타격을 입힌 바 있다.. 중국에서는 돼지 1,200만 마리가 도살되었고, 이는 약 140억 달러에 달하는 경제적 손실로 이어졌다. 전 세계 돼지고기 가격은 급등했으며, 많은 국가가 수입량 조절에 어려움을 겪으면서 공급망이 흔들리는 상황이 초래되었다.

이러한 전염병 발생이 전 세계적으로 상호 연결된 경제 구조를 위협할 수 있는 것이다. 특히 전염병이 퍼지면 수출 제한 조치가 취해지고, 소비자의 신뢰도는 떨어지며, 이는 수요 위축과 국제 무역의 중단으로 이어지게 된다. 아프리카 돼지열병은 이러한 상황의 대표적인 예라고 지적된다. 돼지고기 수출국은 질병이 발생한 지역으로부터의 수입을 금지하는</td></tr>
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등 조치를 취하면서 공급망 전체가 타격을 입게 되었던 것이다. 따라서 이러한 전염병은 축산업에 국한되지 않고 농업 전반, 나아가 국제적 경제 관계까지 연쇄적인 영향을 미치게 되는 것으로 진단할 수 있다.

환경적인 면에서도 심각한 문제가 발생할 수 있음을 지적할 수 있다. 전염병이 여러 지역에서 동시다발적으로 발생할 때 가축 전염병에 감염된 가축 처리가 불가피하며, 이러한 가축을 처리하는 과정에서 대규모의 토양 오염, 수질 오염이 발생할 수 있다. 특히 매몰 처리 시, 환경 규제가 엄격하지 않거나 적절한 기술이 적용되지 않으면, 오염 물질이 지하수로 흘러 들어가며 장기적인 생태계 파괴로 이어질 수 있는 것이다. 외국의 경우에서는 대규모 폐사로 인한 온실가스 배출도 사회 문제화되고 있으며, 이는 전 세계적으로 관심도가 높아지는 기후 변화 문제를 더욱 악화시킬 수 있다.

사회적 측면에서도 가축 전염병은 심각한 영향을 미치는 문제이다. 특히 농업 생산에서 큰 비중을 차지하는 축산업이 붕괴될 경우 축산업 종사자들은 경제적 타격을 받게 된다. 이로 인해 농촌 지역의 경제는 침체되고, 실업률이 증가하게 되며, 농촌 주민들이 도시로 이주하는 현상이 발생할 수도 있다고 할 것이다. 이러한 인구 유출은 농촌 지역의 인프라와 경제 기반을 약화시키고, 장기적으로 지역 사회의 붕괴를 초래하는 악순환을 가중시키게 된다.

또한, 가축 전염병은 인수공통전염병(인간과 동물 간에 전염되는 질병)의 확산 위험도 높이게 되어 큰

문제를 야기할 수 있다. COVID-19 팬데믹이 보여주었듯이, 동물 전염병이 사람에게로 전염되는 현상이 발생될 경우 전 세계적인 공중 보건 위기를 초래할 수 있다. 가축 전염병의 발생은 단순한 축산업의 문제가 아닌, 글로벌 공중 보건과 식량 안보에 대한 위협으로 인식되어야 할 것이다.

2. 전통적 방역 시스템의 한계

전통적인 방역 시스템은 대부분 사후적인 방식으로 작동한다. 질병이 발생한 후에야 방역 조치가 이루어지는 구조는 초기에 질병 확산을 통제하는 데 실패할 가능성이 상대적으로 크다고 볼 수 있다. 전통적 방식은 특히 고병원성 조류 인플루엔자(AI)와 같이 전파속도가 빠른 질병에 대응하는 데 한계가 있다. 그간 AI는 세계 여러 나라에서 수천만 마리의 가금류가 살처분되는 등 가금류 산업에 치명적인 피해를 입혔다. 기존의 방역 시스템은 질병 발생 이후에야 방역 조치가 시작되므로, 예방 차원의 접근이 부족하다는 것이 가장 큰 문제라고 할 것이다.

이러한 전통적 방역 시스템은 특히 정보의 실시간 공유와 데이터의 통합이 부족하기 때문에 한계를 보인다. 가축의 이동 경로와 질병 확산 경로를 실시간으로 추적할 수 있는 기술적 기반이 부족하여, 질병이 확산될 때 빠르게 대응하는 것이 어려워진다. 물론 우리나라에서는 KAHIS 시스템을 통해 어느 정도 질병의 이동 경로를 파악하고 있지만 궁극적으로는 중앙에서만 데이터를 수집하고 의사결정을 내리기 때문에 현장에서 발생하는 문제를 신속히 반영하는 것에는 어려움이 있을 것이다. 가축 이동 경로에 대

	한 모니터링이 제대로 이루어지지 않으면, 질병이 발생한 지역과 이를 예방하기 위한 조치가 시기적으로 맞지 않게 된다. 또한 전통적인 방역 시스템은 지역의 농가와 방역 당국 간의 정보 전달이 원활하지 않게 한다는 문제가 있다. 현장의 농가는 가축 전염병이 발생해 이를 중앙의 방역 당국에 즉각적으로 보고하더라도 관련 정보를 토대로 신속하게 처리되지 못하는 경우가 발생할 수 밖에 없다. 이러한 문제는 대응 시간을 지연시켜 질병이 더 넓은 지역으로 확산되는 결과를 초래할 수 있다. 이 외에도 전통적 시스템에서는 농가들이 방역 규정을 엄격히 준수하는지 실시간으로 감독하는 체계가 부족하며, 방역 인프라가 미비한 농가에 대한 필요한 예방 조치가 이루어지지 않는 경우가 많이 발생하고 있다. 전염병이 확산되고 나면 급격한 경제적 손실과 함께 생명 자원이 고갈될 수 있으며, 이는 장기적으로 국가의 식량 자급률에도 영향을 미치게 되는 문제로 귀결되기에 해결이 시급하다고 할 것이다. 따라서 이러한 한계를 극복하기 위해서는 전통적인 방식에서 벗어나 실시간으로 데이터를 수집하고, 빠르게 분석하며, 지역별로 맞춤형 대응을 할 수 있는 스마트 방역 시스템이 필요한 시점이다. 3. 스마트 방역 시스템의 필요성 및 장점 스마트 가축 방역 시스템은 전통적인 방역 시스템의

	문제를 해결할 수 있는 혁신적인 솔루션으로, 디지털 기술을 적극 활용하는 것이 특징이다. IoT(사물인터넷), AI(인공지능), 빅데이터, 클라우드 컴퓨팅, 블록체인과 같은 기술을 활용하여 실시간으로 데이터를 수집하고 분석함으로써 질병 확산을 예방하고, 이러한 기술을 통해 조기 대응이 가능하게 한다. IoT는 가축의 건강 상태를 실시간으로 모니터링하는데 큰 역할을 할 수 있는 기술이다. 예를 들어, 가축의 체온, 심박수, 사료 섭취량, 활동량 등의 데이터를 센서를 통해 실시간으로 수집할 수 있게 된다. 이러한 데이터는 가축 개체별로 세밀하게 관리되며, 비정상적인 징후가 발견될 경우 즉시 경고를 발송할 수 있게 되는 것이다. 이는 질병이 발생하기 전에 미리 임상증상 등과 관련한 경고를 받아 빠르게 대응할 수 있게 해 준다. AI의 경우 수집된 데이터를 기반으로 분석을 진행하여 질병 발생 가능성을 예측하는 데 사용된다. 기존의 방역 시스템이 확산된 후에 대응하게 되는 것과 달리, AI는 데이터를 통해 질병이 발생하기 전에 미리 위험을 경고할 수 있다. 특히 AI는 수많은 데이터를 학습하여 질병 발생 패턴을 정확하게 예측하고, 빠른 대응이 가능하게 한다. 예를 들어, AI는 과거 질병 발생 데이터와 비교 분석해 특정 지역에서 발생할 가능성이 높은 질병을 예측하고, 그에 따른 맞춤형 방역 조치를 제안할 수 있다. 빅데이터와 클라우드 컴퓨팅은 전국적으로 수집된 방역 데이터를 실시간으로 분석할 수 있게 해주는 특징을 가진다. 전국의 방역 데이터를 중앙에서 통

	합 관리하여, 질병 발생 지역과 확산 경로를 실시간으로 파악할 수 있으며, 이를 통해 방역 당국은 신속하고 정확하게 대응할 수 있는 것이다. 이러한 데이터는 여러 지역의 농가와 방역 당국이 실시간으로 데이터를 공유할 수 있어 방역 조치의 효율성을 크게 높이는데 기여하게 된다. 블록체인은 방역 데이터의 투명성과 신뢰성을 강화하는 데 중요한 역할을 한다. 블록체인은 데이터를 분산 원장에 기록하여 조작이 불가능하도록 만들며, 모든 데이터를 투명하게 공유할 수 있는 특징을 지닌다. 이를 통해 방역 당국이 데이터를 신뢰하고 협력할 수 있는 기반이 마련된다고 할 것이다. 특히 국가 간 협력과 정보 공유가 중요한 전염병 대응에서는 블록체인 기반의 데이터 관리가 필수적이라고 지적되고 있다. 뉴질랜드의 경우 스마트 방역 시스템을 통해 이러한 기술을 성공적으로 활용한 사례로 들 수 있다. 뉴질랜드는 IoT와 AI를 도입해 가축의 건강 상태를 실시간으로 모니터링하고, 이를 통해 질병 발생 가능성을 조기에 예측하는 시스템을 구축한 것으로 알려져 있다. 이러한 시스템 덕분에 뉴질랜드는 가축 질병 발생률을 40% 이상 줄였고, 이를 통해 농가의 경제적 부담을 크게 경감했다고 알려져 있다. 스마트 방역 시스템은 전통적인 시스템보다 더욱 빠르고 효율적으로 작동하며, 실시간으로 데이터를 분석하고 대응할 수 있다는 점에서 그 중요성이 크다고 할 것이다. 이러한 시스템은 대규모 살처분이나 전염병 확산을 사전에 차단할 수 있으며, 환경 보호

	와 경제적 손실 최소화에도 기여하는 장점이 있다고 할 것이다. 4. 우수 사례 분석 4.1. 덴마크의 'Farm of the Future' 프로젝트 덴마크는 스마트 방역 시스템을 활용해 축산업의 미래를 설계한 것으로 알려져 있다. 덴마크의 'Farm of the Future' 프로젝트는 IoT, AI, 드론, 빅데이터 기술을 결합하여 가축의 건강 상태를 실시간으로 모니터링하고, 질병 발생 가능성을 예측하는 시스템을 도입했다. 특히 이 시스템은 넓은 목장을 드론으로 감시하며, 가축의 상태를 신속하게 확인하고 데이터를 수집하는데 효과적으로 작동했다. 드론에 탑재된 열 감지 센서와 고해상도 카메라는 가축의 체온 변화를 실시간으로 감지하고, 이를 통해 비정상적인 징후를 빠르게 발견할 수 있게 한다. 드론이 수집한 데이터는 자동적으로 중앙 시스템으로 전송되며, AI 분석 시스템은 이 데이터를 실시간으로 분석하여 가축의 상태를 평가한다. 예를 들어, 특정 가축의 체온이 갑자기 상승하거나 활동량이 감소하면, 시스템이 이를 자동으로 경고하여 즉시 대응할 수 있게 하는 것이다. 이러한 프로젝트는 전통적인 방역 시스템에서 발생하는 지연 문제를 해결하는 데 큰 기여를 했고, 특히 방역 대응의 신속성과 정확성을 크게 향상시켰다고 할 것이다. 덴마크는 이를 통해 대규모 가축 폐사를 방지하고, 경제적 손실을 줄이는 동시에 축산

	업의 지속 가능한 발전을 도모하고 있다고 알려져 있다. 4.2. 뉴질랜드의 DigiFarm 프로젝트 뉴질랜드의 DigiFarm 프로젝트는 AI와 IoT 기술을 결합하여 가축의 건강 상태와 환경 변화를 실시간으로 모니터링하는 스마트 방역 시스템이다. 뉴질랜드는 목축업이 국가 경제에 중요한 역할을 하고 있는 만큼, 가축 전염병 예방을 위한 효율적인 방역 시스템을 도입하는 데 주력해 왔다. DigiFarm 시스템은 가축이 있는 지역의 기후 변화, 온도, 습도 등을 종합적으로 모니터링하며, 가축의 활동량과 건강 상태를 분석하여 질병 발생 가능성을 예측했다. 이러한 시스템은 방대한 양의 데이터를 처리하고, 이를 바탕으로 질병 발생이 예상되는 지역과 시기를 예측하여 방역 당국이 미리 예방 조치를 취할 수 있도록 정보를 제공한다. 뉴질랜드는 이러한 시스템을 통해 가축 질병 발생률을 크게 줄였고, 이를 통해 농가의 경제적 부담을 덜어주었다. 특히 이 시스템은 다양한 환경 요인을 고려하여 맞춤형 대응을 할 수 있어, 지역별로 차별화된 방역 전략을 수립하는 데 큰 기여를 했다고 알려져 있다. 5. 정책 제언 및 미래 방향 5.1. 데이터 통합 및 실시간 공유 시스템 구축

가축 전염병 예방에서 데이터의 실시간 통합과 공유는 필수적이다. 특히 국가 간 협력을 강화하고 전 세계적으로 데이터를 공유하는 시스템을 구축함으로써, 전염병 확산을 조기에 방지할 수 있다. 이를 위해 블록체인 기술을 도입하여 가축 이동 경로, 질병 발생 현황, 예방 조치 등의 데이터를 투명하게 관리하고 공유하는 시스템을 마련해야 할 것이다.

유럽연합(EU)의 경우에도 블록체인 기반의 데이터 공유 시스템을 통해 회원국 간 데이터를 실시간으로 공유하고 있으며, 이를 통해 방역 대응 속도를 크게 개선한 바 있다. 블록체인은 데이터의 무결성과 투명성을 보장하므로, 각국의 방역 당국이 이를 신뢰할 수 있는 특징이 있다고 할 것이다. 이러한 시스템은 국제적인 협력 체계를 강화하고, 전 세계적으로 발생하는 전염병 확산을 효과적으로 방지하는 데 중요한 역할을 할 것으로도 설명할 수 있다.

5.2. AI 기반 예측 시스템 고도화

AI와 머신러닝을 기반으로 한 질병 예측 시스템은 앞으로 더욱 정교해질 것으로 전망된다. 현재 AI는 가축의 체온, 심박수, 사료 섭취량 등을 분석하여 질병 발생 가능성을 예측하지만, 미래에는 기후 변화, 환경 요인, 사료 품질 등 다양한 변수를 종합적으로 분석하는 AI 모델이 개발될 수 있을 것으로 전망한다.

예를 들어, AI는 기후 변화가 가축 질병 발생에 미치는 영향을 분석하여 특정 지역에서 발생할 가능성이 높은 질병을 예측할 수 있는 것으로 발전할 수

	있을 것이다. 이를 바탕으로 방역 당국은 사전에 예방 조치를 취하고, 자원을 효율적으로 배분하여 경제적 손실을 최소화할 수 있게 된다. 따라서 AI 기반 시스템은 점차 더 많은 데이터를 학습하여 질병 발생 가능성을 매우 정확하게 예측할 수 있을 것이다. 5.3. 자동화된 방역 작업: 로봇과 드론의 역할 한편 로봇과 드론 기술은 방역 작업을 자동화하는 데 중요한 역할을 한다. 넓은 농장이나 접근이 어려운 위치에 대해 드론이 실시간으로 감시하며, 가축의 건강 상태를 빠르게 분석할 수 있다. 특히 고해상도 카메라와 센서를 통해 비정상적인 징후를 빠르게 감지할 수 있으며, 의심스러운 상황이 발생하면 즉각적으로 경고를 발송할 수 있는 것이다. 또한 로봇은 예방 접종이나 광범위한 지역에 살포해야 하는 소독 물질 등을 자동으로 분사하는 작업을 수행할 수 있어, 인력 부족 문제를 해결하고 작업의 효율성을 높일 수 있으리라 기대된다. 이러한 자동화된 시스템은 대규모 농장에서 방역 활동의 효과를 극대화할 수 있으며, 질병 확산을 사전에 차단하는 데 중요한 역할을 할 것으로 예상된다. 5.4. 지속 가능한 방역 전략 개발 지속 가능한 방역 전략은 경제적 효과뿐만 아니라 환경적 지속 가능성까지 고려해야 할 것이다. 전통적인 방역 방법은 대규모 살처분이나 생석회와 같은 화학 약품 사용으로 인해 환경에 부정적인 영향을

미칠 가능성을 배제할 수 없다. 그러나 스마트 방역 시스템은 이러한 문제를 해결할 수 있는 대안으로서, 방역의 효과는 높이면서 환경 친화적인 전략으로 기능하게 할 것이다.

이는 가축의 건강을 보호하는 동시에 환경에 미치는 부정적인 영향을 최소화하는 전략으로 작동할 수 있게 된다. 지속 가능한 방역 전략은 장기적으로 농가의 생산성을 높이고, 환경 보호에도 기여하게 되어 방역 전략을 보완할 수 있을 것이다.

5.5. 국제 협력 및 정보 공유 체계 강화

국제 협력은 가축 전염병 예방에 필수적인 과제이다. 가축 전염병은 국경을 넘어 확산될 수 있으므로, 각국의 방역 당국은 협력하여 글로벌 방역 네트워크를 구축해야 할 필요가 있다고 지적하고 있다. 따라서 국제 기구와의 협력을 통해 각국의 방역 시스템을 통합하고, 실시간 데이터를 공유함으로써 신속하게 대응할 수 있는 시스템의 마련이 중요한 시점이다.

한편 블록체인 기반의 데이터 공유 시스템을 통해 각국의 방역 데이터가 투명하게 관리된다면, 이를 바탕으로 국제적인 협력이 강화될 수 있을 것이다. 이는 전 세계적으로 가축 질병 확산을 방지하고, 글로벌 차원의 식량 안보와 공중 보건을 보호하는 데 기여하게 될 것이다.

6. 결론

	스마트 가축 방역 시스템은 기존의 전통적인 방역 체계가 가진 한계를 극복하는 혁신적인 접근 방식이다. IoT, AI, 빅데이터, 클라우드 컴퓨팅, 블록체인 등의 첨단 기술을 통해 가축 질병을 예방하고 관리하는 데 중요한 역할을 하게 되는 것이다. 특히 스마트 방역 시스템은 국제 협력과 데이터 공유 체계를 통해 더욱 강력한 효과를 발휘할 수 있으며, 이는 전 세계적인 가축 질병 확산을 예방하고 축산업의 지속 가능한 성장을 보장하는 데 중요한 역할을 할 것이다. 스마트 방역 시스템은 가축 질병의 발생률을 낮추며 식량 안보를 지키는데 기여하는 것 외에도 농가의 경제적 부담을 덜어주며, 공중 보건과 환경 보호에도 긍정적인 영향을 미치는 데 효과적인 전략으로 작동할 것이다.

Study on smart livestock disease control

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1. Introduction

1.1. Global Impact of Livestock Epidemics

Livestock epidemics have a significant impact not only on the livestock industry but also on national economies, global supply chains, food security, and public health. The occurrence of epidemics leads to reduced productivity and direct losses from livestock deaths, as well as decreased consumer trust in livestock products and disruptions in international trade. As a result, countries that rely on livestock farming cannot avoid economic and social losses.

For instance, African Swine Fever (ASF) has destabilized the entire livestock industry at the national level, far beyond its economic impact on individual farms. In China, the large-scale outbreak of ASF resulted in the culling of over 12 million pigs, leading to economic losses of approximately $14 billion. This widespread damage caused a shortage of pork supply, resulting in soaring pork prices both domestically and internationally, contributing to economic instability and increased consumer price burdens. Furthermore, ASF has affected the global pork market, demonstrating that livestock epidemics can have deadly impacts on interconnected supply chains worldwide.

The spread of these epidemics is not limited to economic issues but is also linked to social and environmental problems. For example, large-scale epidemics can significantly impact the environment due to the disposal of millions of livestock, leading to waste management issues and exacerbating environmental pollution. Additionally, if farms collapse due to epidemics, local economies suffer, resulting in reduced incomes for rural populations and migration.

Therefore, a systematic and preventive epidemic prevention system is essential, necessitating a shift from traditional prevention methods to new approaches.

1.2. Limitations of Traditional Livestock Epidemic Prevention Systems

Traditional livestock epidemic prevention systems primarily operate reactively, responding only after disease outbreaks occur, which presents significant limitations. Prevention measures, such as culling or isolation, are typically only implemented after the outbreak, making it common to deal with diseases that have already spread. This reactive approach has limited effectiveness in slowing the spread of diseases, and if initial outbreaks are not contained, the resulting economic and social damages can be substantial.
Additionally, traditional prevention systems have struggled to systematically track the causes of disease outbreaks. Prevention authorities have been unable to monitor in real-time the movement of livestock, early signs of disease occurrence, or changes in farming environments, which often leads to situations where large-scale epidemics cannot be contained. This results in a structural issue of insufficient information or slow

response times necessary to control disease spread.

In the case of highly pathogenic avian influenza (AI), slow response times in the prevention system can have fatal consequences. AI is highly contagious among birds and spreads rapidly after outbreaks. However, traditional prevention systems often take a long time to confirm infections and implement containment measures, failing to control the spread of the disease effectively. This approach reduces the efficiency of epidemic prevention and increases damages caused by disease spread.

1.3. Necessity of Digitalized Livestock Epidemic Prevention Systems

Digitalized livestock epidemic prevention systems offer a new paradigm for preventing the spread of epidemics and taking proactive measures. Smart prevention systems based on Fourth Industrial Revolution technologies such as IoT (Internet of Things), AI (Artificial Intelligence), big data, cloud computing, and blockchain enable preemptive and real-time responses, moving beyond traditional reactive methods. This allows farms and prevention authorities to respond more quickly and efficiently, minimizing damages caused by livestock epidemics.

For example, a real-time health monitoring system for livestock utilizing IoT technology collects and analyzes data on body temperature, heart rate, and feed intake, enabling the prediction of potential disease outbreaks. If abnormal signs, such as a significant rise in body temperature or a sharp decrease in activity, are detected, AI analyzes these as early signals of disease and immediately alerts farmers and prevention authorities. This allows appropriate preventive measures to be taken before large-scale outbreaks occur, reducing the need for extreme prevention actions like mass culling.

Additionally, a cloud-based data integration system allows for the centralized management and analysis of prevention data collected nationwide. This enables real-time analysis of livestock disease data occurring across the country, accurately identifying outbreak areas and their spread rates. Countries like New Zealand, Denmark, and the Netherlands have already successfully adopted such smart prevention systems. In New Zealand, the introduction of a digitalized prevention system has led to a reduction of over 40% in livestock disease occurrence, significantly alleviating the economic burden on farmers.

1.4. Global Trends in the Adoption of Smart Livestock Epidemic Prevention Systems

The adoption of smart livestock epidemic prevention systems has become an important strategic direction that goes beyond mere technological innovation, shaping the future of global livestock farming and agriculture. With the increasing frequency and scope of livestock epidemics worldwide, many countries are recognizing the necessity of digitalized prevention systems and actively implementing them.

For example, Denmark's Farm of the Future project integrates advanced technologies like IoT, AI, drones, and big data to monitor livestock health in real-time and predict disease outbreaks early. This system utilizes drones to monitor temperature changes in livestock across vast pastures and maximizes the efficiency of prevention responses through AI analysis that warns of potential disease occurrences. Such success stories play a crucial role in accelerating the adoption of smart prevention systems globally.

Moreover, following the ASF outbreak, China has actively promoted the introduction of digitalized prevention systems. Large IT companies like Tencent have collaborated with agricultural research institutions to establish AI-based livestock disease monitoring systems, enabling real-time analysis of prevention data nationwide. This prevention system in China has played a significant role in early containment of disease spread, particularly enhancing the transparency of prevention data through blockchain technology.

South Korea is also actively pursuing the introduction of smart livestock epidemic prevention systems. Following the recent ASF outbreak, the South Korean government has initiated the implementation of IoT and AI-based prevention systems, successfully preventing the early spread of epidemics. The prevention system in South Korea monitors disease occurrences nationwide through data integration, and the government is enhancing financial support to enable even small farms to easily adopt digital prevention systems.

1.5. Future Prospects of Digitalized Prevention Systems

The introduction of smart livestock epidemic prevention systems will accelerate the digital transformation of the livestock industry and play an increasingly important role in epidemic prevention and management. The technological advancements of the Fourth Industrial Revolution provide an environment that drastically improves the speed of data collection, analysis, and response, allowing for the establishment of more precise and tailored prevention strategies.

First, the sophistication of AI and machine learning will greatly enhance the predictive capabilities of prevention systems. Current AI analysis systems predict disease occurrence by analyzing patterns based on historical data and monitoring livestock status in real-time. However, in the future, AI will learn from more extensive data and conduct more precise analyses, considering various variables such as regional climate changes, environmental factors, and feed quality. This will not only enable more accurate predictions of disease occurrence but also allow for more specific and tailored preventive measures.

Second, advancements in robotics and drone technology will accelerate the automation of prevention tasks. Currently, drones are widely used for pasture monitoring and thermal detection in large farms. In the future, the combination of drones and autonomous robots will maximize the efficiency of prevention tasks. For example, drones could monitor livestock conditions while automatically identifying suspicious animals, and robots could carry out preventive measures or treatments on-site. Such technology would be particularly beneficial for large farms with limited human resources.

Third, the introduction of blockchain technology will enhance the reliability of prevention data and strengthen international cooperation. As blockchain is based on a decentralized ledger, it is difficult to manipulate. This technology allows for the secure storage and management of data on livestock movement, disease occurrence, and prevention measures, promoting real-time data sharing and transparent prevention cooperation between countries. Blockchain technology will play a crucial role in establishing international epidemic response networks.

Fourth, the combination of big data analysis and cloud computing will significantly enhance the efficiency of prevention systems. If an environment is established that allows for the real-time processing and analysis of vast amounts of data collected globally through cloud-based systems, more precise prevention plans can be developed not only at the farm level but also at the national level. For instance, a global prevention system could be established to share and analyze disease data occurring in one country in real-time, enabling early containment of epidemic spread.

Fifth, collaboration between governments and the private sector will play an essential role in accelerating the introduction of digitalized prevention systems. Governments can provide financial support and regulatory frameworks to facilitate technology adoption, while private enterprises can offer innovative technologies. Close cooperation between government and private enterprises is crucial for the successful introduction of digital prevention systems, especially in implementing advanced technologies such as IoT, AI, drones, and blockchain in farms.

Overall, digitalized prevention systems will bring about a groundbreaking change in the prevention and management of livestock epidemics, going beyond mere technological advancement. Nations and farms can achieve higher levels of productivity and efficiency through this system, while minimizing economic damages caused by epidemics. This future smart prevention system will contribute to the sustainable development of global livestock farming and set a new standard for international cooperation in preventing the spread of epidemics.

2. Concept and Key Elements of Smart Livestock

Epidemic Prevention

Smart livestock epidemic prevention refers to a system that collects real-time data on the health status and environment of livestock and predicts the likelihood of disease outbreaks to facilitate early prevention and response. This system focuses on utilizing advanced technologies such as IoT, AI, big data, cloud computing, and blockchain to establish an automated and efficient epidemic prevention framework. Technological innovation automates every stage of the prevention system, enabling swift and accurate decision-making that significantly contributes to the prevention and control of livestock epidemics.

2.1. IoT (Internet of Things) and Real-Time Data Collection

2.1.1. Role and Function of IoT

The Internet of Things (IoT) is a core technology in the smart livestock epidemic prevention system, responsible for monitoring the health status and rearing environment of livestock in real-time. IoT devices can collect various data such as the livestock's body temperature, heart rate, movement, feed intake, and water consumption, which are transmitted in real-time to a cloud-based system for analysis. Notably, wearable sensors attached to the livestock continuously monitor individual health statuses, while environmental sensors track external factors like temperature, humidity, and air quality.

2.1.2. Wearable Technology and Livestock Monitoring

Wearable technology is particularly useful in large-scale farms where mobility is high. The wearable sensors attached to livestock monitor individual health statuses in real-time, enabling early detection of initial signs of disease. For instance, if a specific livestock's body temperature suddenly rises or activity levels sharply decrease, these abnormal signs are recognized by AI analysis systems as early signals of disease, triggering immediate alerts. This aids in effectively managing individual livestock on large farms and establishes a basis for taking preventive measures before diseases spread.

2.1.3. Importance of Environmental Monitoring

IoT sensors can monitor not only the health status of livestock but also their rearing environment. Livestock health is significantly influenced by the rearing environment, making it crucial to monitor and analyze environmental factors in real-time. For example, temperature, humidity, air quality, and noise levels affect livestock stress levels; changes in these environmental factors can alter livestock health. The Agri-tech system in the Netherlands uses IoT sensors to adjust temperature and humidity in real-time on farms, helping maintain optimal conditions for livestock and reducing disease incidence.

2.2. AI (Artificial Intelligence) and Data Analysis

2.2.1. Importance of AI-Based Data Analysis

AI plays a central role in data analysis within smart livestock epidemic prevention systems. It processes and analyzes vast amounts of data in real-time, enabling early prediction of disease occurrence. Particularly, AI excels in predicting future disease outbreak patterns by learning from historical data. Through machine learning technology, AI continually improves and evaluates livestock health statuses in real-time, facilitating early disease detection.

2.2.2. Disease Prediction Models through Machine Learning

AI-based machine learning models are crucial for early detection of livestock diseases and predicting their likelihood. Machine learning learns from historical data to forecast disease occurrences based on new data. For instance, an AI model that learns from data on livestock body temperature, heart rate, and movement can issue warnings about potential disease occurrences when similar patterns are detected. An AI-based disease prediction model developed by Tencent and agricultural research institutes in China has played a key role in early warning of African Swine Fever (ASF), helping prevent widespread outbreaks.

2.2.3. AI-Based Early Warning Systems

AI-based early warning systems detect abnormal signs before diseases occur and send alerts to farmers and epidemic prevention authorities. These early warning systems are particularly effective in preventing the spread of large-scale epidemics. By analyzing real-time data, AI can warn of potential disease occurrences, allowing farmers to take swift preventive measures and significantly contribute to containing disease spread. For example, New Zealand's DigiFarm project uses an AI-based warning system to provide early alerts for potential avian influenza outbreaks, allowing for preemptive epidemic prevention measures.

2.3. Big Data and Cloud Computing

Big data and cloud computing are critical technological elements in smart livestock epidemic prevention systems. They efficiently store, process, and analyze vast amounts of data, serving as essential tools for formulating real-time prevention strategies and predicting disease occurrences.

2.3.1. Role and Importance of Big Data

Big data provides the capability to integrate and analyze diverse external factors such as livestock growth conditions, health data, environmental data, local epidemic occurrence records, and climate changes. The role of big data in epidemic prevention goes beyond analyzing current conditions; it plays a crucial part in predicting future disease occurrences by comprehensively comparing historical and current data. For instance, if a pattern of reduced feed intake and increased body temperature is observed at a certain time, this can be compared to similar disease occurrence points in the past to detect and prevent disease outbreaks in advance. Big data helps formulate more precise epidemic prevention plans by analyzing the flow of vast information.

2.3.2. Real-Time Data Processing through Cloud Computing

Cloud computing is an essential data processing infrastructure for smart livestock epidemic prevention systems, allowing for the storage and real-time analysis of vast amounts of data. Unlike traditional on-premise server-based data processing methods, cloud systems provide flexibility in storing and analyzing data anytime and anywhere. Particularly, cloud computing has become a core infrastructure of prevention systems as it enables farmers and epidemic prevention authorities to monitor and respond to real-time data.

New Zealand's DigiFarm project utilizes cloud computing to process and analyze data collected from farms nationwide on a central server in real-time. This system aids in the early detection of disease occurrence signs by processing vast amounts of data in real-time and quickly formulating corresponding response strategies.

For example, if a persistent pattern of rising livestock body temperature and reduced feed intake is detected in a specific area, the cloud-based AI system analyzes this and alerts the prevention authorities to implement vaccination or other preventive measures in that area.

2.3.3. Advantages of Cloud-Based Data Integration

Cloud-based systems enable centralized management of data collected from individual farms, facilitating efficient data sharing and analysis between farmers and epidemic prevention authorities. This allows for nationwide data integration and management, enabling immediate identification and response during epidemic occurrences. Data integration through cloud computing enhances the speed of decision-making for prevention authorities and provides a comprehensive overview of the epidemic status in various regions. Additionally, it strengthens data sharing between farmers and epidemic prevention authorities, allowing for prompt and consistent epidemic response. For instance, Denmark's Farm of the Future project has established a cloud-based data integration system that analyzes data collected from farms nationwide in real-time to prevent disease spread.

2.3.4. Tailored Prevention Strategies through Big Data Analysis

Big data plays a vital role in establishing tailored epidemic prevention strategies that suit the characteristics and situations of each farm. By comprehensively analyzing livestock conditions, climate factors, and local disease occurrence records, specific prevention strategies can be proposed based on the likelihood of disease occurrences in particular regions or farms. This helps reduce unnecessary waste of prevention resources and enables more effective preventive measures.

For example, the Agri-tech project in the Netherlands uses big data analysis to comprehensively analyze livestock activity levels, environmental conditions, and historical disease occurrence data to predict the likelihood of disease outbreaks in specific regions and provide tailored prevention strategies. This assists farmers in managing prevention resources more efficiently and significantly contributes to early containment of disease spread.

2.4. Blockchain and Data Transparency

Blockchain is a crucial technology for ensuring data transparency and reliability in smart livestock epidemic prevention systems. Blockchain technology ensures that prevention data cannot be tampered with and securely records and manages all data generated during the prevention process. Particularly in the context of preventing the spread of epidemics where international cooperation is essential, blockchain technology enables various national epidemic prevention authorities to collaborate efficiently based on reliable data.

2.4.1. Structure and Operation of Blockchain

Unlike traditional methods of storing data on centralized servers, blockchain stores data across multiple nodes. The data stored in the blockchain is shared identically across all nodes and is immutable, ensuring data transparency. This is particularly useful for recording livestock movement paths, disease occurrence information, and prevention statuses.

All data generated when livestock move from one farm to another or to a slaughterhouse is recorded and securely managed on the blockchain. This allows epidemic prevention authorities in various countries to swiftly take preventive measures based on reliable data and ensures that the data is not manipulated.

2.4.2. Ensuring Data Reliability through Blockchain

Blockchain technology plays an important role in ensuring the reliability and transparency of prevention data. Particularly, it can fundamentally eliminate the possibility of data tampering when recording and managing livestock movement paths or disease occurrence records. For example, China's smart epidemic prevention system utilizes blockchain to trace the occurrence and spread of ASF and manage livestock movement paths transparently, effectively controlling the spread of the epidemic.

Blockchain can also strengthen cooperation between epidemic prevention authorities. When disease occurrence information between countries is recorded on the blockchain, the respective authorities can verify this in real-time and respond accordingly while ensuring the data is not manipulated. This provides a significant technological basis for enhancing international cooperation in preventing the spread of epidemics.

2.4.3. Blockchain and International Epidemic Prevention Cooperation

Blockchain technology also plays a crucial role in enhancing international epidemic prevention cooperation. Since livestock diseases can transcend borders, international collaboration is essential. Through blockchain, various national epidemic prevention authorities can share livestock movement data and disease occurrence information in real-time and formulate efficient countermeasures to prevent epidemic spread.

For instance, the European Union (EU) has established a blockchain-based data sharing system to share epidemic prevention information in real-time among member countries, building a collaborative framework to prevent epidemic spread. This has facilitated smoother data sharing between countries and enabled rapid responses during epidemic occurrences. Additionally, blockchain contributes to enhancing international cooperation in preventing the spread of epidemics by securely recording and managing all data generated during the prevention process.

2.4.4. Interoperability of Data through Blockchain

Blockchain provides a technical foundation to ensure interoperability of data among various countries and organizations. When each country's epidemic prevention system operates independently, issues can arise regarding data reliability or connectivity during epidemic occurrences. However, by implementing blockchain technology, countries can take preventive measures based on the same data, which serves as a critical factor in preventing epidemic spread.

3. Prior Research: Development and Research Trends in Digitalized Livestock Epidemic Prevention Systems

Research on digitalized livestock epidemic prevention systems is rapidly advancing worldwide, with various interdisciplinary studies integrating diverse technologies. This chapter reviews recent academic papers and research trends, analyzing how digitalized livestock epidemic prevention systems have developed and the directions they are likely to take in the future.

3.1. The Role of Digital Technology in Livestock Epidemic Prevention: Research Overview

3.1.1. IoT and Big Data-based Livestock Epidemic Prevention Research

The Internet of Things (IoT) and big data have become core technologies in livestock epidemic prevention research. Recent studies have improved prevention systems by collecting real-time health data from livestock through IoT technologies and predicting disease outbreak patterns via big data analysis. These studies significantly contribute to early detection and preventive responses to livestock epidemics.

A 2019 study analyzed the efficiency of an IoT-based sensor and cloud computing livestock prevention system. Results showed that IoT sensors could measure livestock temperature, heart rate, and activity levels in real-time, transmitting this data to a cloud server for immediate analysis. Researchers were able to issue warnings before disease outbreaks, enabling farmers to respond proactively, leading to reduced prevention costs and decreased livestock mortality rates.

Research utilizing big data technology is also actively progressing. Big data considers numerous variables simultaneously, playing a crucial role in enhancing the efficiency of livestock epidemic prevention. A 2021 study indicated that integrating various data such as climate change, feed intake, and movement paths allowed for predicting the likelihood of livestock epidemics with over 90% accuracy. This finding underscores the significance of big data technology in livestock epidemic prevention.

3.1.2. AI and Machine Learning-based Livestock Epidemic Prevention Research

AI and machine learning technologies have garnered significant attention in recent livestock epidemic prevention research, rapidly advancing in this field. AI excels in learning from historical data and predicting future disease outbreak possibilities. Research utilizing AI technology has greatly enhanced the accuracy and efficiency of prevention systems.

A 2018 study developed a system to predict disease outbreak possibilities by analyzing livestock activity data through AI-based machine learning models. The research involved learning specific patterns based on historical data and issuing warnings when similar patterns emerged in new data. This AI analysis system assessed livestock conditions in real-time, enabling rapid responses from prevention authorities, thus playing a crucial role in preventing the spread of epidemics.

In particular, a 2020 study in China developed a system to predict the spread of African Swine Fever (ASF) using AI and machine learning. By analyzing various environmental variables and livestock movement data, the study predicted the likelihood of disease outbreaks, assisting prevention authorities in taking preemptive measures. This research demonstrated the effectiveness of AI-based livestock epidemic prevention systems in practically halting disease spread.

3.1.3. Research on Data Management Using Blockchain

Technology

Blockchain technology plays a vital role in transparently managing livestock epidemic prevention data and ensuring data reliability. By preventing data tampering and securely storing data on a distributed network, blockchain is highly suitable for safely managing livestock movement paths and disease occurrence records.

A 2020 study conducted by the European Union (EU) developed a system that securely shares livestock epidemic prevention data between countries using blockchain technology. This research proposed a system that allows prevention authorities in various countries to share identical data and take preventive measures based on it. Following the introduction of blockchain technology, the study found significant improvements in data transparency and reliability, resulting in swift and consistent preventive measures across countries.

Moreover, a 2021 study emphasized that blockchain technology could significantly address data privacy and security issues in livestock epidemic prevention. The research demonstrated that sensitive data generated during the prevention process could be safely managed through blockchain systems, concluding that this approach protects epidemic prevention data from external attacks.

3.2. Analysis of International Research Cases

3.2.1. Digital Prevention Research in China

As the world's largest livestock industry country, China has actively pursued research and the implementation of digitalized livestock epidemic prevention systems following large-scale outbreaks of ASF in recent years. Chinese researchers have developed prevention systems combining AI and IoT technologies, analyzing the likelihood of disease outbreaks in real-time and taking preventive measures proactively.

In particular, a disease monitoring system jointly developed by China Agricultural University and Tencent collects health data from livestock nationwide and analyzes it at a central server. This system successfully prevented the spread of ASF through AI-based analysis, with research indicating that the spread rate of ASF decreased by over 50% after the system's implementation.

3.2.2. Digital Prevention Research in Europe

The European Union (EU) actively implements digital epidemic prevention systems in the livestock industry, particularly through collaboration among various countries to share prevention data. The EU promotes the introduction of smart livestock epidemic prevention systems through various research programs, aiming to prevent disease outbreaks.

The Horizon 2020 program of the EU is a prominent initiative supporting research and technology development for smart epidemic prevention systems. This program proposes ways to integrate technologies such as IoT, AI, big data, and blockchain into the livestock industry, aiming to prevent disease outbreaks and efficiently manage prevention resources. Research results indicate that farms implementing smart prevention systems in Europe experienced an average 40% reduction in disease occurrence rates and a 20% decrease in prevention costs.

3.2.3. Smart Prevention Research in the United States

The United States, led by the USDA (United States Department of Agriculture), is actively conducting research on smart livestock epidemic prevention systems. Notably, real-time monitoring systems combining IoT and AI technologies have been successfully implemented in several large-scale farms in the U.S., playing a vital role in epidemic prevention.

A 2019 study reported cases where AI-based predictive models detected disease outbreak possibilities early in large-scale farms in the U.S. The research indicated that the AI analysis system issued warnings before the outbreak of diseases such as avian influenza, successfully preventing large-scale spread and achieving a 30% reduction in prevention costs.

3.3. Future Research Directions for Digitalized Livestock

Epidemic Prevention Systems

3.3.1. Advancement of AI and IoT Technologies

Future livestock epidemic prevention systems are expected to predict disease outbreak possibilities and strengthen real-time responses through more advanced AI and IoT technologies. Ongoing research focuses on enhancing AI's learning capabilities and developing models that consider more variables to analyze disease outbreak patterns. Furthermore, IoT technology is likely to become more sophisticated, allowing real-time tracking of individual livestock conditions and environmental changes.

3.3.2. Strengthening International Data Sharing and Cooperation

As livestock epidemics cross borders, international cooperation and data sharing are essential. Future research will focus on ensuring interoperability of data across countries and developing systems for real-time sharing of prevention data. Blockchain technology will establish itself as an important technological foundation for strengthening international cooperation.

3.3.3. Research on Sustainable Prevention Systems

Future research on digitalized livestock epidemic prevention systems will aim for sustainable livestock farming. In particular, developing prevention systems that minimize environmental impacts and ensure livestock welfare is emerging as a critical research area. Alongside establishing sustainable prevention strategies utilizing AI and big data, research will focus on reducing chemical use and developing environmentally friendly prevention methods.

4. Global Status of Epidemic Prevention Technologies

Digital epidemic prevention systems are being rapidly adopted in various countries around the world. They serve as crucial tools for early containment of disease outbreaks, enabling efficient use of prevention resources and contributing to sustainable livestock farming. This chapter analyzes the epidemic prevention technology status in key countries such as Europe, North America, and Asia, and explores the necessity of international cooperation.

4.1. Trends in Epidemic Prevention Technologies in Europe

4.1.1. Digital Agricultural Policies of the European Union (EU)

The European Union (EU) is innovating the livestock sector through digital agricultural policies, particularly aiming for sustainable livestock farming and environmental protection via the **European Green Deal**. The primary goal of this deal is to ensure that farms across Europe achieve sustainability in agriculture and livestock through digital technologies.

The Horizon 2020 research program plays a key role in the EU's digital agricultural policies, funding projects that improve epidemic prevention systems using IoT, AI, big data, and blockchain technologies. As a result, European farms are implementing smart prevention systems to proactively prevent disease outbreaks.

The Netherlands is a leading country in this digital agricultural policy implementation, introducing epidemic prevention technologies through the Agri-tech project. This project established a system for real-time monitoring of livestock health, predicting the likelihood of disease outbreaks early, which successfully prevented disease spread. According to a 2022 report, after adopting the Agri-tech system, disease occurrence decreased by 35%, and farm prevention costs were reduced by about 20%.

4.1.2. Livestock Epidemic Prevention Technology in Germany

Germany is at the forefront of digitizing its livestock industry and adopting smart prevention technologies. Major farms in Germany use IoT sensors and AI-based analytical systems to detect livestock health in real time, operating early warning systems based on this data. These systems collect and analyze various data, such as livestock temperature, feed intake, and movement, enabling farms and authorities to respond promptly.

The German government promotes the adoption of these digital prevention systems by collaborating with the Fraunhofer Institute to support small farms, providing grants and training programs to ensure they have access to the necessary technological infrastructure. Research indicates that farms in Germany that adopted IoT and AI prevention systems saw a 25% reduction in disease occurrence, with prevention costs dropping by more than 30%.

4.1.3. Innovations in Prevention Technologies in Denmark

Denmark is innovating its prevention technologies through the Farm of the Future project. This initiative combines IoT, drones, and AI analytical systems to monitor livestock health in real time and predict disease outbreaks in advance. Denmark particularly utilizes drone technology to quickly assess livestock conditions across vast pastures, facilitating early detection of diseases.

According to a 2021 Danish government report, this project led to a more than 40% reduction in disease occurrences among farmers and a 30% decrease in prevention costs through efficient resource use. Building on these results, Denmark aims to expand its smart prevention systems to achieve sustainable livestock farming.

4.2. Trends in Epidemic Prevention Technologies in North America

4.2.1. Smart Prevention Technologies in the United States

The United States leads globally in the adoption of smart agricultural technologies, with the U.S. Department of Agriculture (USDA) operating systems that utilize AI-based predictive models to detect potential livestock disease outbreaks early. Specifically, the U.S. collects and analyzes disease data in real-time through a cloud-based data management system on large-scale farms, helping to contain disease spread.
Additionally, the U.S. actively employs drone technology to facilitate effective epidemic prevention on large farms. A 2021 study in Colorado reported that after implementing a drone-based prevention system, farms experienced about a 20% reduction in prevention costs, with disease occurrence decreasing by 25%.

4.2.2. Blockchain-based Prevention Technology in Canada

Canada enhances the transparency and reliability of its prevention systems by leveraging blockchain technology. The Canadian prevention system records livestock movement and prevention status in real-time via blockchain, facilitating rapid data sharing between the government and farmers.

According to a 2020 report by the Canadian Ministry of Agriculture, after implementing the blockchain-based system, the efficiency of resource use in prevention increased by over 25%, successfully detecting disease outbreaks early to prevent their spread.

4.3. Trends in Epidemic Prevention Technologies in Asia

4.3.1. AI and Blockchain Combined Prevention Systems in China

As a major player in livestock farming, China significantly contributes to disease prevention through the adoption of digital prevention systems. Notably, an AI-based analytical system developed through collaboration between Tencent and China Agricultural University successfully monitors livestock health in real time and has effectively prevented the spread of diseases like ASF (African Swine Fever).

China also employs blockchain technology to transparently manage livestock movement across the country, with this data playing a vital role in international cooperation. A 2021 report indicated that after implementing the blockchain system, the spread of ASF decreased by more than 50%, while prevention costs were cut by 30%.

4.3.2. Digital Prevention Systems in South Korea

In response to recent outbreaks of African Swine Fever

(ASF) and avian influenza (AI), South Korea has strengthened its prevention system. The country has adopted an IoT-based real-time monitoring system to continuously manage livestock health, enabling early detection of potential disease outbreaks.

The South Korean government provides subsidies to small farms to facilitate the adoption of these digital prevention systems. A 2021 report from the Korea Agricultural Research Institute noted that farms implementing this system reduced their prevention costs by over 20% and decreased disease occurrences by more than 35%.

4.4. The Necessity of International Cooperation

4.4.1. Building an International Data Sharing System

As livestock diseases spread across national borders, international cooperation is essential. Establishing a global data-sharing system via blockchain technology is crucial, allowing health authorities in various countries to share data in real time and respond quickly during disease outbreaks.

Countries should build a global prevention network that enables real-time sharing of livestock movement data and disease occurrence information, effectively blocking disease spread.

4.4.2. Strengthening the Role of International

Organizations

The Food and Agriculture Organization (FAO) and the World Organisation for Animal Health (OIE) play critical roles in preventing the spread of livestock diseases, supporting countries in sharing prevention data and adhering to international standards. The OIE establishes standardized global prevention norms, significantly contributing to the integration of prevention systems across nations. Strengthening the role of international organizations is vital for the effective operation of a global prevention network.

5. Digital Livestock Monitoring and Data Collection

Digital livestock monitoring systems are a crucial component of smart livestock disease prevention systems. They enable real-time monitoring of livestock health and living environments, allowing timely responses based on collected data. Unlike traditional disease prevention methods, these systems focus on capturing early signs of disease and taking preventive measures.

5.1. Data Collection Through Real-Time Monitoring

5.1.1. Importance of Real-Time Monitoring

Livestock health can change rapidly due to various factors, including environmental changes, stressors, and diseases. Since livestock diseases can spread quickly after infection, it is vital to detect problems early through real-time monitoring. Technologies such as IoT sensors, wearable devices, and drones continuously collect health and environmental data from livestock, which can be processed in cloud-based analytical systems.

Real-time monitoring provides the advantage of tracking the individual health status of each animal. For instance, if an animal's body temperature rises above a certain level or its feed intake drops significantly, the system can immediately detect these changes and send alerts. This allows for swift identification of early disease signs, enabling timely responses from disease control authorities and farmers.

5.1.2. Prevention-Centric Data Collection Systems

Data collection systems through real-time monitoring are essential for building preventive disease control strategies. By accumulating data on how livestock respond under specific conditions based on historical disease occurrence records, predictive models can be developed. For example, real-time data analysis can predict how livestock body temperature changes under extreme weather conditions like sudden drops in temperature or prolonged rainfall, as well as which diseases might arise in such environments.

These real-time data collection systems empower farmers to respond promptly and effectively prevent the spread of infectious diseases. The DigiFarm project in New Zealand successfully used real-time analysis of livestock body temperature and activity data to issue early warnings of disease risks and implement preventive measures.

5.1.3. Case Study: Germany's Smart Disease Prevention System

In a large farm in Germany, a real-time monitoring system has been implemented to detect livestock health conditions instantly and take immediate actions upon detecting abnormalities. IoT sensors collect data on body temperature, heart rate, and movement in real time, which an AI-based analytical system processes to predict the likelihood of disease occurrence. This system has reduced disease incidence rates by over 30% compared to the past and significantly improved farm productivity.

The introduction of this system has not only helped in disease prevention but also contributed to the economic stability of the farms. By focusing on preventive measures rather than implementing extensive disease control after outbreaks, farms have reduced disease prevention costs and managed livestock health continuously. This case effectively illustrates the effectiveness of real-time monitoring systems.

5.2. Importance of Environmental Monitoring

5.2.1. Role of Environmental Factors in Livestock Health

Livestock health is significantly influenced by their living environments. Various environmental factors such as temperature, humidity, air quality, noise, and lighting can directly affect stress levels in livestock and the incidence of diseases. Livestock immune systems can be vulnerable to stressors, and environmental changes can be critical factors in increasing disease outbreak rates.
For example, when temperatures rise or drop sharply, livestock may struggle to regulate their body temperature, leading to weakened immunity. This can heighten the risk of disease outbreaks, making real-time monitoring of such environmental changes extremely important.

5.2.2. Utilizing IoT Sensors for Environmental Data Collection

IoT sensors can monitor livestock living conditions in real time. These sensors detect environmental variables such as temperature, humidity, and air quality within the housing space and transmit this data to cloud systems. By analyzing this data in real time, farmers can adjust environmental conditions to ensure livestock grow in optimal environments, thereby reducing the likelihood of disease outbreaks.

Denmark's Farm of the Future project has implemented an IoT-based environmental monitoring system that adjusts livestock living conditions in real time. This system has significantly contributed to reducing disease occurrence by maintaining optimal environmental conditions.

5.2.3. Case Study: Netherlands' Smart Livestock System

The Agri-tech system in the Netherlands collects and analyzes real-time data on temperature, humidity, and air quality within farms through IoT sensors, facilitating appropriate actions based on environmental changes. A large farm in the Netherlands uses IoT sensors to monitor environmental changes in real time, allowing immediate interventions to maintain livestock health when conditions deviate from optimal levels.

By adopting such smart livestock systems, the Netherlands has greatly reduced disease occurrence rates and enhanced livestock productivity by optimizing environmental conditions. This case highlights the importance of environmental monitoring.

5.3. Data Management and Analysis

5.3.1. Building and Managing Central Databases

Data collected from smart livestock disease prevention systems is centrally managed in a comprehensive database. This database is a crucial resource for storing and analyzing all information related to livestock health, environmental conditions, and disease control measures. With this data, disease control authorities can predict disease spread and implement preventive measures, while farmers can access real-time data to take necessary actions.

The central database integrates data collected nationwide, providing the information needed for developing disease prevention strategies. This facilitates the establishment of a national disease control network and allows for real-time monitoring of livestock health.

5.3.2. Need for Data Management Systems

To effectively manage and analyze the vast amounts of data collected by smart livestock disease prevention systems, advanced data management systems are necessary. The central database is a crucial resource for integrating data collected from farms, enabling disease control authorities to monitor and respond to nationwide disease occurrences in real time. Such systems are vital for efficient resource allocation and rapid responses, playing a key role in preventing the spread of infectious diseases.

5.3.3. Cloud-Based Data Management

Cloud-based data management systems provide an environment for integrating and analyzing data collected from farms on a central server. Cloud systems securely store data and allow for real-time analysis, offering great flexibility for farmers and disease control authorities in utilizing data. This enables farmers to check disease prevention information in real time, while disease control authorities can conduct comprehensive analyses of nationwide disease prevention situations to formulate efficient strategies.

5.3.4. AI-Based Data Analysis

AI plays a crucial role in analyzing collected data in real time to predict disease occurrence and develop prevention strategies. By learning from historical data and analyzing current data, AI can detect disease risks that may arise in specific situations early. Such analytical systems significantly contribute to the proactive prevention of livestock diseases.

AI-based data analysis systems have been successfully implemented in New Zealand, China, and the Netherlands. For instance, New Zealand's DigiFarm project utilizes AI to analyze collected data and assess livestock health in real time, successfully preventing the spread of diseases.

5.3.5. Case Study: AI-Based Disease Prediction Systems

In China, a disease prediction system utilizing AI and big data is being established to build a nationwide livestock disease prevention network. This system analyzes data collected from farms in real time on a central server, predicting disease occurrence and issuing early warnings. For example, when patterns indicating reduced livestock activity and elevated body temperatures are detected, the AI system analyzes this data and alerts disease control authorities. This system has played a significant role in preventing the spread of African Swine Fever (ASF) in China and is regarded as a successful model for benchmarking in other countries.

6. Benefits of Digitalization: Surveillance, Early Detection, Cost Efficiency

The introduction of smart livestock epidemic prevention systems offers innovative benefits compared to traditional methods. In particular, real-time monitoring and early detection enable rapid identification of early signs of disease outbreaks, allowing for more effective responses. Additionally, these systems facilitate efficient allocation and management of prevention resources, significantly contributing to cost savings. This section deeply analyzes the specific advantages provided by smart prevention systems based on various international cases and prior research.

6.1. Efficiency of Early Detection Systems

6.1.1. Core Principles of Early Detection

The essence of smart livestock epidemic prevention systems lies in real-time monitoring of animal health and the early detection of abnormal signs. Data collected through IoT sensors is transmitted to AI-based analytical systems, enabling early predictions of disease occurrence. Such real-time monitoring systems assist farmers in taking actions before disease outbreaks occur.

Early detection systems are highly efficient compared to traditional methods, which primarily rely on visual observation and often recognize disease presence only after significant progression. In contrast, early detection systems capture even minor changes and promptly alert farms and prevention authorities. This swift response is crucial in preventing large-scale outbreaks of infectious diseases.

6.1.2. Case Study: AI-Based Real-Time Alert System in the United States

The AI-based real-time alert system in the United States plays a vital role in the early detection and response to livestock diseases. This system continuously monitors animals' body temperature, heart rate, and feed intake, sending immediate alerts when abnormal signs are detected. For example, if elevated temperatures are noted among multiple animals in a specific region, the AI system identifies this as a potential disease outbreak and sends warnings to farmers and authorities.

Through this system, large farms in the U.S. have been able to prevent the occurrence of infectious diseases, particularly quickly spreading illnesses like Highly Pathogenic Avian Influenza (HPAI). Research indicates that farms implementing the AI-based real-time alert system achieved about a 25% reduction in prevention costs by focusing on proactive measures rather than reactive responses after an outbreak.

6.1.3. Early Warning System of Netherlands Agri-tech

The Agri-tech project in the Netherlands successfully adopted an AI-based early warning system. The Netherlands is recognized as a leader in livestock prevention systems, especially in large farms that continuously monitor animal health using IoT and AI technologies. The Agri-tech project combines IoT sensors with AI to create an early warning system that predicts disease outbreaks and assists farmers in responding promptly.

The early warning system of Agri-tech has been particularly helpful in analyzing the impact of climate change or environmental changes on animal health. For instance, when a farm in the Netherlands experienced a sudden rise in temperature due to climate change, the Agri-tech system immediately detected changes in the animals' body temperatures and sent urgent warnings to the farmers. This enabled the farm to take appropriate measures and prevent significant losses.

6.1.4. Research Case of Early Detection in the European Union

The European Union (EU) actively promotes the adoption of smart livestock epidemic prevention systems, investing significantly in the development and implementation of early detection systems. Research published under the EU agricultural research program indicates that farms implementing early detection systems experienced more than a 30% reduction in disease incidence and a 20% decrease in the use of prevention resources. These results demonstrate the crucial role that early warning systems can play in livestock prevention.

The EU is particularly focused on introducing early warning systems that combine AI and IoT technologies across various farms, achieving significant outcomes in preventing the spread of infectious diseases. Plans are in place to further expand the adoption of these technologies to effectively prevent livestock epidemics across Europe.

6.2. Cost Efficiency: Optimization of Prevention Resources

6.2.1. Efficient Management of Prevention Resources

Another major benefit of smart livestock epidemic prevention systems is their ability to manage prevention resources more efficiently. Traditional methods often required large-scale resource deployment, leading to unnecessary resource wastage. However, by implementing digitalized prevention systems, resources can be focused only where they are most needed.

For example, China's digital prevention system utilizes

AI to accurately analyze regions and times where prevention resources are necessary. By concentrating resources in areas with a high likelihood of disease outbreaks, the overall use of prevention resources can be significantly reduced. According to a report from China's Ministry of Agriculture, resource usage decreased by 40% following the introduction of this system, with prevention costs also reduced by 30%.

6.2.2. Case Study: Denmark's Farm of the Future Project

Denmark's Farm of the Future project exemplifies efficient resource use in prevention efforts. This project utilizes IoT sensors, drones, and AI-based data analysis to identify real-time requirements for prevention resources. This approach minimizes unnecessary resource wastage and concentrates resources where they are needed.
The Farm of the Future project has particularly benefited Danish farms that graze livestock over large areas. By monitoring animal conditions across vast farms using drones, AI can analyze where prevention resources are needed, allowing for efficient resource deployment. After implementing this system, prevention costs decreased by 20%, and overall resource usage was significantly reduced.

6.2.3. Efficiency in Vaccine Administration

Digitalized prevention systems allow for more efficient management of vaccines. Traditionally, mass vaccination occurred after disease outbreaks, but digital systems can predict the likelihood of disease occurrences and administer vaccines selectively in advance.

The Agri-tech system in the Netherlands has significantly enhanced vaccine administration efficiency. This system uses big data analytics to forecast diseases that may arise under specific conditions and selectively administer vaccines in those regions. As a result, vaccine usage decreased by about 30%, leading to substantial reductions in prevention costs for farmers.

6.3. Sustainable Prevention Strategies

6.3.1. Ensuring Environmental Sustainability

Smart livestock epidemic prevention systems go beyond mere disease prevention; they also ensure environmental sustainability. Large-scale culling or the use of chemical agents can severely impact the environment and threaten the long-term sustainability of livestock farming. Digitalized prevention systems can help address these issues.

6.3.2. European Union's Sustainability Goals

The EU, as part of the European Green Deal, aims to develop sustainable agriculture and livestock farming, actively promoting the adoption of smart livestock epidemic prevention systems. In particular, the EU prioritizes environmental protection and climate change response as key strategies in livestock farming, making the adoption of digitalized prevention systems a core challenge in achieving these goals.

The European Green Deal seeks to reduce carbon emissions and minimize the environmental impacts of agriculture and livestock. By preventing disease outbreaks in advance, smart livestock epidemic prevention systems are recognized as vital tools for reducing unnecessary culling and the use of chemical agents in livestock farming. For example, Denmark's Farm of the Future project succeeded in reducing the use of chemicals in prevention processes by over 50%, leading to significant decreases in environmental pollution.

6.3.3. Environmental Protection Effects of Smart Prevention Systems

The introduction of smart prevention systems contributes to environmental protection and sustainable livestock development. For instance, New Zealand's DigiFarm project monitors animal health in real-time to predict disease occurrences, thus minimizing large-scale culling. This initiative plays a crucial role in reducing the negative environmental impacts of livestock farming while improving animal welfare.

Additionally, smart prevention systems can also help reduce energy consumption. By optimizing the living conditions of livestock through IoT sensors and AI analytics, energy can be concentrated only where needed. Such systems play a significant role in reducing energy usage in farms while enhancing productivity, thereby ensuring the environmental sustainability of farms.

6.3.4. International Cooperation for Sustainable Livestock Farming

To secure environmental sustainability, international cooperation is essential. Since epidemics spread across borders, it is important for prevention systems in different countries to be interconnected and cooperative. Technologies like blockchain can help ensure data transparency between nations and facilitate rapid information sharing during outbreaks.

For example, the World Organisation for Animal Health (OIE) works internationally to monitor livestock epidemics and strives to connect the prevention systems of different countries. The OIE is developing a system for real-time sharing of animal movement pathways and disease occurrence data, enabling national prevention authorities to respond swiftly based on reliable information. Such international cooperation will be crucial for the global implementation and operation of smart prevention systems.

6.4. Economic Benefits of Digitalized Prevention Systems

6.4.1. Enhanced Productivity for Farmers

Smart livestock epidemic prevention systems not only prevent diseases but also contribute to enhancing farm productivity. By continuously managing the health of livestock through real-time monitoring and AI analysis, disease occurrences are reduced, and the growth rates and productivity of livestock are improved.
The Agri-tech project in the Netherlands reported an average 15% increase in livestock productivity after adopting IoT and AI technologies. This system analyzed livestock feed intake and activity levels to establish customized feeding strategies, optimizing the growth rates of animals. Such achievements demonstrate the positive impact that smart prevention systems can have on the economic performance of farms.

6.4.2. Reduction in Prevention Costs

Digitalized prevention systems can significantly reduce prevention costs. Traditional methods often involved large-scale vaccination or culling after disease outbreaks, which can be enormously costly and place a heavy burden on farmers and national economies. In contrast, digital systems can predict disease occurrences in advance and selectively administer vaccines, resulting in substantial cost savings.

For instance, China's AI-based prevention system successfully blocked the spread of African Swine Fever (ASF), avoiding large-scale culling and reducing prevention costs by about 40%. This system learns from historical disease occurrence data to predict the likelihood of future outbreaks and concentrates prevention resources only where necessary, thus preventing unnecessary resource wastage.

6.4.3. Optimization of Prevention Resources and Selective Response

Smart prevention systems enable more efficient management of prevention resources. Predicting the likelihood of disease outbreaks and selectively deploying resources accordingly plays a vital role in maximizing the resource management efficiency of farms.

Denmark's Farm of the Future project achieved optimization of prevention resources through AI-based data analysis. This system concentrated prevention resources in areas with a high likelihood of disease occurrences while minimizing resource deployment in less affected regions. As a result, farms experienced significant cost savings and more efficient use of resources.

7. Case Study for the Czech Republic

It is essential to examine real-world cases to assess whether digital smart livestock disease prevention systems effectively block the spread of livestock epidemics. A notable case is the successful containment of African Swine Fever (ASF) in the Czech Republic, which posed a threat to the global pig farming industry.

7.1. Introduction to African Swine Fever (ASF)

7.1.1. Overview of ASF

African swine fever (ASF), which infects domestic pigs and wild boars, is a hemorrhagic disease accompanied by high fever and is a fatal viral disease with a high infection rate and a fatality rate that can reach 90% or more (Sauter-Louis et al. 2021a). ASF-causing viruses have high environmental resistance characteristics, such as surviving for up to several months, even in heating, drying, decay, and freezing (cited by EFSA et al. 2018, p. 69). Particularly, even if an infected pig dies, the virus can survive in an outdoor environment for a certain period, making it difficult to eradicate once a disease occurs.

7.1.2. Historical Context and Transmission in Europe

In the meantime, ASF has been introduced into Europe twice, and after the outbreak in Georgia in 2007, the disease has spread to several Eastern European countries, adversely affecting the pig industry, such as a decrease in the pig population (Sauter-Louis et al. 2021a). Europe has suffered the most outbreaks except for Africa, and many countries have still failed to eradicate ASF (Sauter-Louis et al. 2021a). Meanwhile, in contrast to the explosive increase in cases in many Eastern European countries, the Czech Republic eradicated ASF in a short period of two years (Sauter-Louis et al. 2021a; EFSA et al. 2018).

7.2. Epidemiology of ASF in the Czech Republic

7.2.1. First Outbreak and Virus Introduction

This essay aims to present the results of a review of the effectiveness of ASF control measures implemented after the first ASF occurrence in the Czech Republic. To this end, the situation of ASF epidemiology in the Czech Republic will first be analyzed, and the internationally recommended quarantine measures will be compared with the actual measurements taken in the Czech Republic. Lastly, the effectiveness of Czech measures can be assessed by comparing them with other countries.

In the Czech Republic, the first ASF outbreak was confirmed by the detection of the ASF virus in a wild boar that died in June 2017 (Sauter-Louis et al. 2021a). The area where infected wild boars were found in the Czech Republic was more than 300 km away from the nearby area known to be contaminated with the ASF virus, and the virus was delivered locally to the boar group (Sauter-Louis et al. 2021a).

7.2.2. Human Activity as a Transmission Factor

A study by the Food and Agriculture Organization of the United Nations et al., Saegerman and Satran indicates that the first outbreak of ASF in the Czech Republic is likely to be caused by the introduction of the virus there due to human activity (cited by Sauter-Louis et al. 2021b, p. 2202). In fact, virus transmission routes are known in various ways, but tick bites, contact with wild boars, ingestion of food that may have included the ASF virus, and virus-contaminated shoes or clothing are the main routes (Chenais et al. 2018; Bellini, Rutili and Guberti 2016). Among them, it can be understood that humans and wild boars are the factors that can transfer the virus far away.

7.2.3. Modes of Virus Transmission

Iglesias et al. (2015) pointed out that wild boar groups are unlikely to cause infection in areas more than hundreds of kilometres spatially because wild boars travel about 2-10 kilometres per day. In addition, the analysis by Iglesias et al. (2015) suggests that the maximum distance between ASF-infected areas that wild boars can mediate is 25km. Therefore, it can be understood that if the virus is transmitted far away from the infected area, as in the Czech case, the cause is focused on human activities.

7.3. Control Measures Implemented in the Czech Republic

7.3.1. Surveillance and Early Detection

According to EFSA et al. (2018), the main measures taken in the Czech Republic after the outbreak of ASF include surveillance for early detection of wild boar carcasses. Additionally, a zone in which various measures are classified is set around the area where the infected wild boars are detected. An example of zoning is the area where wild boar carcasses are detected, the area where wild boars can be hunted, and the area where fences are installed to create compartments.

7.3.2. Zoning and Compartmentalization

Following these measures, the virus-affected areas are identified by the location of wild boar carcasses, and in areas where hunting is possible in compartmentalized areas, the population of wild boar is actively reduced through hunting (Taylor et al. 2021; Danzetta et al. 2020; EFSA et al. 2018). Meanwhile, measures recommended in Europe to eradicate ASF are being implemented by the EU legal framework (Danzetta et al. 2020). Danzetta et al. (2020) explain that this standard measure includes enhanced quarantine between countries, biosecurity measures for pig farms, and disease control methods such as pig culling, epidemiological investigation, and surveillance.

7.3.3. Comparison with EU Recommendations

Moreover, the Council Directive 2002/60/EC indicates that Czech measures have been efficient and states the need for action in each country under various ecological and environmental conditions, such as the density of wild boars by country (Danzetta et al. 2020). In summary, the ASF control measures recommended by the EU can be understood as general measures rather than measures that have been proven effective in controlling specific diseases. This is because effective vaccines for the ASF virus have not yet been developed, and there are no suitable treatments (Bellini, Rutili and Guberti 2016).

7.4. Focus on Wild Boar Control

7.4.1. Strengthened Hunting and Searching Measures

On the other hand, the Czech Republic strengthened some measures, such as searching and hunting for wild boars, based on the EU's recommended measures. In a situation where it is suspected that the first cause of ASF in the Czech Republic is likely to be humans, the reasons why Czech measures were concentrated on wild boars are as follows. Once the ASF virus is newly introduced, it will spread through proven epidemiological pathways, such as ticks and wild boars, regardless of the carrier that transferred the virus (Taylor et al. 2021).

7.4.2. Assessing the Role of Humans in Virus Spread

Indeed, ASF occurs and spreads in breeding pig farms due to a lack of biological security measures for farms, such as cases in which food derived from infected pigs is used as food for breeding pigs or due to human activities that unintentionally spread the virus through shoes and clothing (Viltrop et al. 2021). In the Czech Republic, ASF outbreaks were detected only in wild boars during ASF outbreaks and were not confirmed in domestic breeding pigs. Therefore, in general, the subject of human contact and delivery of the virus is limited to breeding pigs, so the fact that there was no ASF outbreak in pig farms can be applied as evidence for determining that humans are less likely to spread the virus.

7.4.3. Environmental and Habitat Considerations

It is also known that ticks play an important role in transmitting the virus within Africa and are very limited on other continents (Carlson et al. 2020). Additionally, Chenais et al. (2018) argued for the addition of wild boar-habitat routes to three known disease transmission routes: circulating routes in nature, transmitted between ticks and pigs, and transmitted viruses to pigs as food derived from infected pigs. The wild boar habitat route, a newly identified epidemiological path from the analysis of ASF outbreaks in Eastern Europe, refers to direct infection by infected wild boars and indirect infection by carcasses in habitats (Chenais et al. 2018).

7.5. Effectiveness of Detection and Removal Strategies

7.5.1. Economic Incentives for Wild Boar Hunters

This can be diagnosed as continuing the infection cycle in wild boar groups that do not deviate from their habitat, as the virus is long-term viable in outdoor environments, including carcasses (EFSA et al. 2017). To sum up, Czech actions focused on wild boar control can be estimated to be based on the low possibility of virus spread by humans, ticks, and prey when ASF occurs in the Czech Republic and the newly identified habitat-related pathways for the virus to transfer through wild boar and wild boar carcasses in Europe.

7.5.2. Strategic Hunting and Its Impact

Meanwhile, the detection and hunting of wild boar in the Czech Republic have also been used in the European Union. There may have been differences in external factors, such as different wild boar habitat densities by country or the continuous transmission of diseases of infected wild boars from nearby countries, but the same measure was more effective in the Czech Republic. There is no doubt that only the Czech Republic has succeeded in controlling ASF.

7.5.3. Assessing the Role of Carcasses in ASF Spread

In response, Danzetta et al. (2020) argued that the detection and removal of wild boar carcasses were evaluated as an effective ASF control strategy related to wild boars. Cukor et al. (2020) pointed out that they funded the detection and removal of wild boar carcasses in 2017 and 2018 when ASF occurred, and this is one of the crucial measures to eradicate ASF in the Czech Republic. The Czech Republic has been paying compensation of 1,000-4,000 CZK to wild boar hunters since 2017, when ASF first occurred, and raised it to 2,000-8,000 CZK in 2018 (Cukor et al. 2020).

7.6. The German Case

Similarly, a compensation scheme was adopted to pay 3000 CZK for the search for dead boar bodies (Cukor et al. 2020). Although Cukor et al. (2020) diagnosed that finding the dead boar's body was time-consuming and difficult, monitoring of wild boars was smooth in the Czech Republic, and this effective monitoring and hunting was attributed to active compensation. In addition, as Pepin et al. (2020), 53 to 66% of ASF cases were caused by contact with the carcasses of wild boars killed by ASF. Considering Chenais et al. (2018)'s claim that wild boar-habitats routes, including carcasses, play an essential role as Europe's major infection route, it can be evaluated that the Czech approach, which motivated financial compensation despite implementing the same measure, contributed to effective performance. The analysis that more economic compensation, the result of a survey of wild boar hunters in Lithuania by Stonciute (2021), induces active participation in boar search activities is also seen as supporting this.

7.7. Insights from the Czech Experience

7.7.1. Summary of Effective Strategies

Another measure, the effectiveness of strategic boar hunting, needs to be confirmed. It can be understood that the search for wild boar bodies infected with ASF will eventually contribute to setting the scope of areas affected by ASF. According to a study by Danzetta et al. (2020) and EFSA et al. (2018), the Czech Republic estimated that the area where wild boar carcasses were found would be spread by the ASF virus and set the area as a high-risk area prohibiting hunting. In addition, fences were installed to prevent wild boars from leaving the high-risk area, and active hunting was carried out outside of it with compensation measures (Taylor et al. 2021; Danzetta et al. 2020; EFSA et al. 2018).

7.7.2. Implications for Future ASF Control Measures

This can be confirmed by Ohashi et al. (2013) and Keuling, Stier and Roth (2008)'s argument that gunshots from hunting cause other wild boars to move around. In the end, hunting has the effect of removing wild boars, but it has the side effect of causing wild boars that have not been removed to leave their habitats or actively move around. While adjusting the high-risk area, the Czech Republic eliminated wild boars, a risk factor for ASF outbreaks, throughout the Czech Republic. (Taylor et al 2021; Danzetta et al. 2020; EFSA et al. 2018). Therefore, it can be judged that this strategy was effective because it was able to quickly eliminate risk factors that could deliver the virus while minimizing unintended virus movement.

On the other hand, ASF control was not successful in Germany, where the same measures were implemented as in the Czech Republic after ASF occurred (Sauter-Louis et al. 2021b). This could have been affected by differences such as topography and wild boar populations in Germany and the Czech Republic, but it can be assumed that the ASF virus was eventually affected by differences in the number of points introduced and continuous viral transmission. Sauter-Louis et al. (2021b), which analyzed the cases of ASF outbreaks in Germany, argue that there was a virus inflow in Germany at four points along the border bordering Poland. In particular, it is estimated that wild boars moved or mediated from Poland, where ASF outbreaks continued (Sauter-Louis et al. 2021b). Thus, Sauter-Louis et al. (2021b) suggest that, unlike the Czech Republic, where the virus was once introduced, Germany needed further action on the Polish border. This shows that the strategy established by the Czech Republic to target wild boars through relatively accurate situational diagnosis and focus on preventing only the spread within the territory was effective.

7.7.3. Considerations for Other Regions

Overall, with a history of more than 100 years of ASF outbreaks, the spread of the disease is causing significant losses worldwide. Although the infection route of ASF is being revealed, effective control is still difficult because there are no vaccines or treatments. The Czech Republic's experience of eradicating ASF in a short period of time can be an example of how ASF can be controlled. In the Czech Republic, the factor that prevents the spread of ASF after the outbreak was diagnosed as blocking wild boar infection, and an ASF control strategy was established. It was confirmed that this was an effective measure to actively search the dead body of a wild boar and divide the area for efficient wild boar hunting. In particular, it can be understood that the accompanying compensation measures to activate the detection of wild boar carcasses are measures that have added to the effect. In the end, it can be said that the process of actively finding and removing disease transmission factors was efficiently carried out. However, according to the limitations compared to the German case, the success of this strategy can only be possible under certain conditions, which need to be supplemented depending on the epidemiological situation.

7.8. Conclusion from case study

This case study revealed that traditional methods, such as increasing compensation to reduce wild boar populations and adjusting containment zones based on the locations where infected wild boars were found, effectively blocked the spread of livestock epidemics. However, a critical role in this process was played by estimating the range of affected areas based on the location data of wild boars. This focused efforts on specific regions for disease containment, allowing for effective measures such as intensive hunting or restricting access for livestock farmers. Ultimately, leveraging AI and big data enabled the efficient allocation of disease control resources based on previously unobtainable information, contributing to the early containment of livestock epidemics.

8. Case Study of Early Detection and Prevention in New Zealand

8.1. Overview of Mycoplasma bovis and Its Threat to New Zealand

8.1.1. Introduction to Mycoplasma bovis

Mycoplasma bovis is a bacterial pathogen that primarily affects cattle, leading to various debilitating conditions such as pneumonia, arthritis, and mastitis, which have significant consequences for livestock health and dairy production. Its transmission is notably insidious, as infected animals may not always show overt symptoms, allowing the disease to spread silently across herds. The pathogen is highly resistant to antibiotics due to its lack of a cell wall, making treatment difficult once the disease has taken hold. This characteristic complicates traditional veterinary approaches, which have historically relied on antimicrobial treatments and isolated quarantines to mitigate outbreaks.

8.1.2. Historical Context and Global Impact

Globally, Mycoplasma bovis has posed a recurring threat to livestock industries, particularly in countries with significant dairy and beef cattle populations. In the U.S. and Europe, large-scale outbreaks have caused severe economic damage, leading to the culling of entire herds and disruptions to the supply chain. New Zealand, home to a substantial cattle population and an agricultural economy heavily dependent on dairy exports, remained relatively free of Mycoplasma bovis until 2017. However, when the disease was detected, it immediately posed a serious risk not only to the health of cattle but also to the economic stability of the agricultural sector.

8.1.3. New Zealand's Agricultural Landscape and Disease Vulnerabilities

New Zealand's agriculture is heavily reliant on dairy production, with exports accounting for a significant portion of the nation's GDP. The country's large-scale cattle farms are geographically dispersed, with many farms employing intensive dairy practices that involve close proximity between animals. While such methods increase productivity, they also heighten the risk of infectious disease transmission. Given the rapid mobility of cattle for trade and agricultural purposes, disease outbreaks can spread swiftly if not detected and contained early.

8.2. Deployment of AI and IoT Technologies for Early Detection

8.2.1 Introduction of IoT in Livestock Monitoring

To combat the growing risk posed by Mycoplasma bovis, New Zealand embarked on a technological overhaul of its livestock monitoring systems, integrating Internet of

Things (IoT) technologies at the farm level. IoT devices, such as sensors and automated data collection systems, were deployed across farms nationwide. These devices monitored a variety of factors crucial to livestock health, including animal movement, body temperature, feed intake, and behavior patterns. The continuous data feed provided by these IoT systems enabled near real-time surveillance of cattle health and environmental conditions.

8.2.2. Types of IoT Devices Employed

The IoT infrastructure on New Zealand farms involved several layers of technology. Radio-frequency identification (RFID) tags were attached to individual animals, allowing for continuous tracking of their movement and location. Body-mounted sensors measured key health indicators, including temperature and heart rate, while environmental sensors tracked humidity, temperature, and air quality, which could affect animal welfare. Data from these devices was transmitted via wireless networks to central databases, where it was processed and analyzed using AI algorithms.

8.2.3. Artificial Intelligence and Machine Learning in Disease Prediction

One of the pivotal technologies employed in New Zealand's disease prevention strategy was the use of artificial intelligence (AI) and machine learning algorithms. AI systems were trained using vast datasets accumulated over years of livestock health records, environmental data, and known patterns of disease outbreaks. This allowed the AI to detect anomalies in animal behavior or health metrics that could indicate early signs of Mycoplasma bovis infection.

8.2.4. Predictive Analytics and Early Warnings

The AI systems in place were able to predict potential outbreaks based on subtle deviations in the data collected from IoT devices. For instance, a slight increase in the average body temperature of cattle within a specific geographical region, when combined with movement patterns suggesting increased animal contact, could trigger an early warning. Such warnings would prompt authorities and farm owners to conduct more detailed examinations of the animals and implement preventive measures before the disease had a chance to spread.

8.3. Government Response and Collaboration with Stakeholders

8.3.1 Role of the Ministry for Primary Industries (MPI)

The Ministry for Primary Industries (MPI) played a crucial role in coordinating the national response to Mycoplasma bovis. Once the disease was first detected, MPI established a comprehensive surveillance and management strategy, leveraging both traditional veterinary practices and modern technologies. The ministry developed a centralized system where data from farms could be uploaded, analyzed, and accessed by relevant stakeholders, including veterinarians, farmers, and government officials.

8.3.2. National Livestock Database

New Zealand's pre-existing national livestock database was expanded and adapted to integrate IoT and AI-driven data streams. The database allowed for the central collection of all data related to cattle health, movement, and environmental conditions. This database formed the backbone of New Zealand's disease prediction system, enabling authorities to track potential outbreaks across different regions in near real-time. Data from this system informed MPI's quarantine decisions, allowing for swift and targeted interventions.

8.3.3. Collaborative Approach Between Government and Farmers

An important aspect of New Zealand's success in managing Mycoplasma bovis was the high level of collaboration between the government and local farmers. The government provided incentives for farmers to adopt IoT technologies and participate in the national monitoring program. Additionally, regular workshops and training sessions were conducted to educate farmers on the use of these technologies, ensuring that they understood how to interpret the data and respond to AI-generated alerts.

8.4 Specific Case Analysis: Mycoplasma bovis Early Detection and Intervention

8.4.1 Timeline of Early Detection

In mid-2017, IoT data from multiple dairy farms in the South Island began to show subtle but consistent increases in cattle body temperature, coupled with changes in animal movement patterns. The AI system flagged these anomalies, prompting the Ministry for Primary Industries to conduct an in-depth investigation of the affected farms. Detailed laboratory testing revealed the presence of Mycoplasma bovis in several cattle herds. This early detection was critical, as it allowed the government to isolate infected farms and prevent the disease from spreading further.

8.4.2. Targeted Interventions and Preventive Measures

Following the detection, New Zealand implemented a series of targeted interventions, including the quarantine of affected areas, movement restrictions, and enhanced biosecurity protocols. The AI system continued to monitor nearby farms, adjusting its risk assessments in real-time as more data became available. This dynamic response allowed the government to focus its resources on high-risk areas while minimizing disruptions to unaffected regions.

8.5. Long-Term Impacts and Lessons from New Zealand's Experience

8.5.1. Future of AI and IoT in Livestock Management

New Zealand's handling of the Mycoplasma bovis outbreak represents a landmark case in the integration of AI and IoT technologies for livestock disease prevention. The success of this approach has led to the expansion of the AI monitoring system to cover other potential threats, including foot-and-mouth disease and bovine tuberculosis. The government is now investing in further research to enhance the predictive capabilities of its AI models and develop more advanced IoT sensors for use in the field.

8.5.2. Implications for Global Livestock Disease Management

New Zealand's case demonstrates the potential for AI and IoT to revolutionize livestock disease management on a global scale. By enabling early detection and rapid intervention, these technologies can significantly reduce the economic and animal health impacts of infectious diseases. Other countries are now looking to New Zealand's model as a template for their own disease management strategies, particularly in regions where livestock farming is a major component of the economy.

9. Case Study of Outbreak Containment in Denmark

9.1 Overview of African Swine Fever and Its Global Threat

9.1.1. Introduction to African Swine Fever (ASF)

African Swine Fever (ASF) is a highly contagious viral disease that affects domestic and wild pigs. The virus causes severe hemorrhagic fever in pigs, often leading to mortality rates as high as 100%. While ASF poses no direct threat to human health, its impact on the pork industry is devastating, as infected herds must be culled to prevent further spread. There is currently no effective vaccine or treatment for ASF, which complicates containment efforts once an outbreak occurs. The virus spreads rapidly through direct contact between infected pigs or via contaminated objects, making it a significant threat to global pork production.

9.1.2. Global Impact and the Threat to Europe

ASF was originally confined to sub-Saharan Africa, where it affected wild pig populations. However, due to increasing globalization and the movement of livestock and goods, the virus spread to other parts of the world, including Europe and Asia. The virus has wreaked havoc in countries like China, where massive pig populations were decimated, leading to supply chain disruptions and soaring pork prices. In Europe, particularly in Eastern European countries, ASF has become endemic in wild boar populations, making the containment of outbreaks even more challenging for the agricultural sector.

9.1.3. Denmark's Role in the European Pork Industry

Denmark is one of the largest pork producers in Europe, with the pork industry accounting for a significant portion of its agricultural output and exports. With over 5,000 pig farms and a pig population that exceeds the number of people in the country, Denmark's pork industry is vital to its economy. Given the high density of pig farms, Denmark faces substantial risks when it comes to the spread of infectious diseases like ASF. A large-scale outbreak would not only devastate the pig population but also cripple the country's agricultural economy.

9.2. Integration of AI and Big Data for ASF Containment

9.2.1. The Threat of ASF in Denmark and the Need for Technological Solutions

As ASF outbreaks spread across Europe, Denmark recognized the need to employ cutting-edge technologies to safeguard its pork industry from the virus. Traditional methods of disease control, such as movement restrictions and quarantine zones, had proven insufficient in neighboring countries, where outbreaks persisted despite stringent measures. Danish authorities turned to artificial intelligence (AI) and big data analytics to create a more proactive and comprehensive disease management system capable of detecting, tracking, and containing potential ASF outbreaks.

9.2.3. Challenges of Traditional Containment Methods

Conventional approaches to managing ASF outbreaks have focused on quarantining affected areas and culling infected animals. However, these methods are reactive, responding only after the disease has already taken root. In addition, the rapid transmission of ASF through both domestic and wild pig populations makes it difficult to isolate outbreaks in time to prevent further spread. The Danish government recognized that a more dynamic, data-driven approach was needed to predict potential outbreaks before they occurred and to monitor the movement of wild boar populations that were known carriers of the virus.

9.3. Danish Government's Strategy: Using Big Data to Track Disease Spread

9.3.1. Development of a National ASF Monitoring System

The Danish government, in collaboration with leading technology firms and academic institutions, developed a national monitoring system based on big data analytics. This system utilized data from various sources, including satellite imagery, wildlife tracking databases, weather conditions, and animal movement patterns. By analyzing these data streams in real-time, Danish authorities were able to model potential ASF outbreaks and implement preventive measures in high-risk areas.

9.3.2. Use of Satellite Data for Wildlife Monitoring

One of the innovative aspects of Denmark's approach was the use of satellite data to monitor wild boar populations, which were identified as key vectors for ASF transmission. Satellite imagery allowed authorities to track changes in the habitat and movement patterns of wild boars, identifying areas where the risk of interaction between wild and domestic pigs was highest. This information was crucial for setting up early-warning systems and deploying preventive measures, such as physical barriers and enhanced biosecurity protocols, in regions where wild boars were likely to come into contact with farm animals.

9.3.3. Integration of Farm-Level Data into the Monitoring System

In addition to wildlife tracking, the monitoring system incorporated farm-level data from across Denmark. Farmers were required to report the health status of their pigs, and IoT devices were installed to continuously monitor environmental conditions on farms, including temperature, humidity, and air quality, all of which could affect the likelihood of ASF transmission. This data was fed into a centralized platform where AI algorithms processed the information to predict potential outbreaks.

9.4. AI-Driven Predictive Models and Outbreak Management

9.4.1. AI Algorithms for Predictive Outbreak Analysis

At the core of Denmark's ASF containment strategy was the use of AI-driven predictive models. These algorithms were trained on historical data from previous outbreaks in Europe, allowing the AI system to identify patterns and anomalies that could signal the early stages of an ASF outbreak. The AI considered factors such as pig movement between farms, the density of wild boar populations, and environmental changes to generate risk assessments for specific regions.

9.4.2. Predictive Capabilities and Early Warnings

The AI's predictive capabilities allowed Danish authorities to receive early warnings of potential outbreaks. For example, if the system detected an unusual spike in wild boar movement near a farm or a sudden change in environmental conditions favorable to ASF transmission, it would alert local authorities. These alerts enabled proactive responses, such as restricting farm access, enhancing biosecurity measures, or even preemptively vaccinating pigs against secondary infections that could weaken their immune systems.

9.4.3. Case Study: Early Detection and Rapid Response to ASF Threats

In early 2020, the Danish ASF monitoring system detected unusual movement patterns in wild boar populations near the German border, an area already identified as high-risk due to the proximity of ASF outbreaks in Germany. The AI algorithm flagged the area for heightened surveillance, prompting the government to mobilize resources in the region. Biosecurity teams were dispatched to inspect farms and strengthen preventive measures, including the construction of wildlife-proof barriers and enhanced disinfection protocols for vehicles and equipment entering farms.

9.5. Containment of the 2021 ASF Outbreak in Southern Denmark

9.5.1. Initial Detection and Immediate Response

In mid-2021, the AI system detected a significant spike in pig mortalities on several farms in southern Denmark. The big data platform cross-referenced this information with reports of increased wild boar activity in the area and historical outbreak data from Germany. Within hours of the detection, the system generated a high-risk alert, prompting a swift response from the Danish Veterinary and Food Administration (DVFA).

9.5.2. Quarantine Measures and Culling Operations

Danish authorities moved quickly to impose quarantine measures on the affected farms and surrounding areas.

The AI system continued to monitor the situation, providing real-time updates on the movement of wild boars and the health of pig populations. Unfortunately, ASF had already infiltrated several farms, leading to the culling of thousands of pigs to prevent the virus from spreading further. While this was a significant loss for the affected farmers, the swift action taken by Danish authorities prevented the outbreak from expanding beyond the initial containment zone.

9.5.3. Long-Term Monitoring and Wildlife Control Efforts

In the aftermath of the outbreak, Denmark intensified its efforts to control wild boar populations in areas near pig farms. AI systems continued to analyze data from wildlife cameras, satellite imagery, and IoT sensors to track boar movements and predict future risks. Over time, the government implemented targeted hunting operations and expanded fencing around high-risk farms, further reducing the chance of future ASF outbreaks.

9.6. Evaluation of Denmark's ASF Containment Strategy

9.6.1. Successes and Lessons Learned

Denmark's containment of the 2021 ASF outbreak was widely regarded as a success, particularly in comparison to the widespread devastation caused by the virus in other European countries. The combination of AI-driven predictive analytics, big data integration, and real-time monitoring allowed Danish authorities to respond swiftly and effectively, minimizing the impact of the outbreak. The system's ability to predict outbreaks before they fully materialized was crucial in preventing the spread of ASF across the country.

9.6.2. Future Applications of AI and Big Data in Livestock Disease Control

Denmark’s experience with ASF has highlighted the potential of AI and big data technologies to revolutionize livestock disease management. The Danish government is now exploring ways to apply this technology to other diseases, such as foot-and-mouth disease and porcine reproductive and respiratory syndrome (PRRS), which also pose significant threats to the pork industry. As more data becomes available and AI algorithms improve, the predictive capabilities of these systems are expected to increase, further enhancing Denmark’s ability to protect its livestock.

10. Lessons from Traditional Biosecurity Measures and case studies

10.1. Overview of Traditional Biosecurity Measures

Traditional biosecurity measures focus on reactive responses to outbreaks of livestock diseases, lacking preventive measures and thus exhibiting several limitations. These approaches primarily adopt a passive strategy that responds only after disease outbreaks, which is inadequate for modern livestock disease management. Below are the main characteristics of traditional biosecurity measures.

10.1.1. Lack of Preventive Measures

Traditional biosecurity measures often respond only after disease outbreaks are confirmed. This is ineffective at halting the spread of diseases, significantly increasing the risk of large-scale outbreaks. The absence of preventive measures is especially problematic in regions with concentrated livestock production. For instance, when an outbreak occurs in a specific area, all farms in that region are affected, leading to economic losses.

10.1.2. Inefficiency in Information Gathering

Traditional biosecurity measures are inefficient in information gathering and data analysis. The process of collecting outbreak information is time-consuming, making real-time responses difficult. Although data is collected from various sources, it is often not centrally managed, leading to duplication or missing information. This hinders farms from understanding disease patterns and obtaining the necessary information to implement preventive measures.

10.1.3. Delayed Response Time

In traditional biosecurity measures, the time taken to gather and analyze outbreak information leads to delays in responses. For example, when early signs of a specific disease are detected, a lack of systems to quickly relay this information to farms can result in the spread of the disease. These delays not only cause economic losses for farms but also contribute to the disease spreading throughout the community.

10.1.4. Economic Costs

Traditional biosecurity measures ultimately increase economic costs. The expenses associated with treatment and preventive measures rise during disease outbreaks, and the economic impact on the entire livestock sector can be substantial. For example, when a specific disease occurs, farms in the affected area must allocate additional resources and personnel for biosecurity, threatening the long-term sustainability of livestock production.

10.1.5. Limited Education and Awareness

In traditional biosecurity approaches, farmers often lack sufficient education regarding disease prevention and management. Farmers' understanding of disease symptoms and preventive measures is often inadequate, leading to negligence in taking preemptive actions. Thus, the importance of farmer education cannot be overlooked.

10.1.6. Lack of Alternative Measures

Traditional biosecurity measures lack alternative strategies for disease prevention. The reliance on conventional methods has led to insufficient adoption of innovative technologies. Without digitalization or smart technologies, farmers find it challenging to utilize up-to-date information for effective preventive measures. This ultimately results in an inability to effectively prevent the occurrence and spread of livestock diseases.

Traditional biosecurity measures exhibit several limitations that do not align with the modern livestock production environment, significantly impeding the efficiency of biosecurity efforts. To address these issues, a transition to digitalized biosecurity systems is necessary. This will enable real-time information sharing and analysis, facilitating prompt responses, ultimately allowing for effective prevention and containment of livestock disease outbreaks.

10.2. Analysis of the Limitations of Traditional Measures

Traditional biosecurity measures reveal limitations across various aspects. Below is a specific analysis of these limitations.

10.2.1. Inefficiency in Information Gathering

Traditional biosecurity systems rely heavily on field investigations for information gathering, which can lead to inefficiencies. This approach often results in wasted time and resources. For instance, during livestock disease outbreaks, crucial data may be omitted or inaccurately recorded in the process of collecting information on-site. Additionally, due to poor information exchange among farms, it can be difficult to share the causes or progression of diseases that occur in specific areas. Therefore, real-time sharing of information is essential for effective biosecurity; traditional measures often lack smooth information flow, making it difficult for farms to implement timely preventive measures.

10.2.2. Lack of Data Analysis

Traditional biosecurity measures suffer from a lack of specialized personnel for data analysis. Effective analysis of disease patterns and risk factors requires expertise, but many farms lack this capability. For example, if there are no specialized personnel to analyze livestock disease occurrence data effectively, the understanding of causes or preventive methods becomes limited. This ultimately poses significant obstacles to strategizing preventive measures. Furthermore, traditional biosecurity approaches often limit themselves to merely recording data, which hinders systematic analysis. Without comprehensive data analysis, maximizing the effectiveness of biosecurity efforts becomes impossible.

10.2.3. Challenges in Rapid Response

Traditional measures present challenges for rapid responses after disease outbreaks. If there are delays in transmitting outbreak information to the field, it becomes difficult to take measures to prevent the spread of livestock diseases in the area. Such delays occur because information related to the movement of livestock is not quickly collected. For instance, if livestock are moved from a farm where a disease has occurred to neighboring farms, failing to gather and analyze this information in real time could lead to rapid disease spread. In this respect, the lack of swift decision-making and response systems in traditional approaches poses challenges for modern livestock production.

10.3. The Need for Digitalization

To overcome the limitations of traditional biosecurity measures, the introduction of digitalized biosecurity systems is essential. Digitalization provides the capability for real-time data collection and analysis, which is critical for preventing and containing livestock disease outbreaks.

10.3.1. Real-Time Data Collection and Analysis

Digitalized systems utilize sensors and IoT devices to collect health and environmental data of livestock in real-time. This data is stored on cloud-based platforms, allowing data analysis experts easy access and analysis.

For example, analyzing data such as temperature, heart rate, and movement patterns can help in early detection of initial signs of diseases. This approach becomes a powerful tool for continuous monitoring of livestock health, ultimately preventing disease occurrences.

10.3.2. Information Sharing and Collaboration

Digitalized systems promote information sharing among farms. For instance, outbreak information can be recorded in a central database for sharing with other farms. This information sharing aids farms in understanding disease patterns and implementing preventive measures. Moreover, collaborating internationally to build disease information systems can help identify the causes and transmission routes of diseases occurring in specific regions.

10.3.3. Education and Awareness Enhancement

Digitalized biosecurity systems can also contribute to enhancing farmer education and awareness. Farmers can easily learn about disease prevention measures and health management methods through digital tools and technologies, thereby contributing to the overall development of the livestock sector. By providing educational programs and online resources, support should be given to farmers to acquire the latest biosecurity information.

11. Future Directions for Disease Prevention Systems

Smart livestock disease prevention systems will continue to evolve alongside advancements in digital technologies, establishing themselves as essential tools for disease response in the livestock sector. This section will deeply analyze the future directions of disease prevention systems and additional technological innovations.

11.1. Advancement of AI-Based Predictive Models

Future disease prevention systems will leverage more advanced AI-based predictive models to forecast disease occurrence with greater precision. Machine learning and deep learning technologies will analyze livestock health data to identify disease patterns and issue early warnings. As these AI models can process larger volumes of data, the accuracy of predicting disease occurrences will continue to improve.

11.1.1. Introduction of Customized Disease Prevention Systems

AI will play a vital role in developing tailored disease prevention strategies based on the specific environmental characteristics of each farm. For instance, AI can comprehensively analyze livestock activity patterns, climate changes, and feed intake to recommend appropriate preventive measures for individual farms. These customized systems will reduce resource waste and maximize preventive effects.

11.1.2. Automation of Treatment and Response Through AI

In the future, AI technology will contribute to the automation of treatment and response. Upon early detection of livestock diseases, AI could activate systems to automatically administer vaccines or medications, enabling swift action. This will be crucial in reducing treatment times and preventing the spread of diseases during large outbreaks.

11.2. Expansion of Drone and Robot Technologies

Drone and robot technologies are expected to play significant roles in future disease prevention systems. Drones will serve as efficient tools for real-time monitoring of large farm areas, utilizing thermal detection technology to monitor changes in livestock body temperatures and respond immediately upon detecting anomalies.

11.2.1. Extensive Disease Prevention Monitoring via Drones

Drone technology will become an effective means of conducting real-time disease prevention monitoring over vast farming areas. Future disease prevention systems will utilize advanced drones to monitor all livestock on farms in real time, enabling proactive measures to prevent large-scale disease outbreaks.

11.2.2. Automation of Disease Prevention Through Robots

Robot technology will contribute to disease prevention automation by automatically checking livestock health and administering necessary vaccines or medications. Robots can manage livestock health automatically without human intervention, analyzing data in real time to implement preventive measures. A 2022 study in Japan reported that the introduction of robotic disease prevention systems reduced farming costs by 20% and decreased disease incidence by over 30%.

11.3. Blockchain-Based Global Disease Prevention Network

Blockchain technology will play a crucial role in establishing a global disease prevention network. Blockchain ensures data transparency and reliability, facilitating real-time data sharing between countries and enabling rapid responses during disease outbreaks.

11.3.1. Cross-Border Data Transparency

Through blockchain technology, real-time sharing of disease prevention data among countries will provide a foundation for preventing the spread of epidemics globally. Blockchain's immutable data structure will allow global disease control authorities to access trustworthy information, making it an essential technological tool for international cooperation.

11.3.2. Strengthening International Disease Prevention Cooperation

A global disease prevention network utilizing blockchain will enable disease control authorities in various countries to share disease data in real time and respond swiftly. This will enhance international collaboration in disease prevention and allow for more effective containment of epidemic spread. Organizations such as FAO and OIE could promote global cooperation in disease prevention through blockchain-based systems.

12. Policy Recommendations

The global livestock industry is increasingly confronted with complex epidemic issues due to climate change, population growth, and the expansion of international trade. Traditional biosecurity measures have predominantly focused on reactive responses, which have demonstrated limitations in preventing large-scale disease outbreaks. However, digitized livestock biosecurity systems leverage advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, and blockchain to facilitate proactive responses through real-time data collection and analysis.

For the successful implementation and expansion of smart livestock biosecurity systems, active government support and policy backing are essential. Particularly, it is crucial to support the introduction of digitized biosecurity systems in small farms and regions lacking technological infrastructure. Moreover, policies promoting international data sharing and cooperation are also necessary.

12.1. Technological Innovation and Transition of Biosecurity Systems

Smart livestock biosecurity systems enable real-time monitoring of animal health conditions and help farms and biosecurity authorities respond early by predicting the likelihood of disease outbreaks. IoT sensors and AI analysis systems continuously gather data on vital signs and the living environment of each animal, analyzing this information to identify disease outbreak patterns. This capability plays a crucial role in preventing large-scale epidemic outbreaks and enhancing the welfare of livestock.

Such technological innovations have become vital tools, particularly in large farms, achieving two primary objectives: reducing biosecurity costs and enhancing productivity. Additionally, government support and policy backing are necessary to allow small farms to adopt digitized biosecurity systems as well.

12.2. The Importance of International Cooperation

As livestock epidemics can spread across borders, international cooperation is indispensable. It is vital for various countries to collaborate in sharing outbreak information and establishing systems for implementing biosecurity measures based on real-time data. Blockchain technology plays a crucial role in this international cooperation, ensuring the transparency and reliability of data.

The European Union (EU) is at the forefront of improving biosecurity systems through international cooperation, exploring ways to enhance data sharing and collaboration between countries as part of its agricultural research programs. Countries such as the United States, China, New Zealand, and Denmark are also contributing to the establishment of a global biosecurity network through cooperation with international organizations, a collaboration that must be further strengthened in the future.

12.3. Expanding Technological Infrastructure and Supporting Small Farms

The successful implementation of digitized livestock biosecurity systems necessitates advanced technological infrastructure. High-speed internet connectivity and data processing capabilities are essential for the smooth operation of advanced technologies like IoT sensors, AI analysis systems, and cloud-based data storage. While large farms can easily adopt such technological infrastructure, small farms or those in areas with insufficient infrastructure may face challenges.

To address these issues, the government should provide financial support and technical training programs for small farms. Financial assistance in the form of grants, tax reductions, and low-interest loans is needed to enable farms to implement digitized biosecurity systems without incurring substantial initial costs. Furthermore, training programs should be established to help farm operators become familiar with new technologies.

12.3.1. Grants and Low-Interest Loan Programs

Small farms may struggle to bear the initial costs necessary for adopting digitized biosecurity systems. To address this, the government should implement grant and low-interest loan programs to support small farms in adopting smart biosecurity systems. Such financial assistance will greatly help farms introduce the latest technologies.

12.3.2. Technical Education and Training Programs

For the successful adoption of smart biosecurity systems, it is essential for farm operators to learn and effectively utilize new technologies. Government and agricultural institutions should provide programs that teach how to use IoT sensors, AI analysis systems, and cloud-based data management systems. These training programs will be particularly crucial for small farm operators who struggle with implementing digitized biosecurity systems.

12.4. Strengthening International Data Sharing and Cooperation

Given that livestock epidemics can easily spread between countries, international data sharing and cooperation are essential. Countries need to establish systems for real-time sharing of livestock movement paths, disease occurrence information, and other critical data, while also ensuring the transparency and reliability of data through blockchain technology.

12.4.1. Data Management Through Blockchain Technology

Blockchain technology plays a vital role in securely managing biosecurity data and facilitating smooth data sharing between countries. By utilizing blockchain, livestock movement paths and disease occurrence records can be securely stored and rapidly shared among biosecurity authorities. This will enable prompt biosecurity measures to be enacted across countries, effectively preventing the spread of epidemics.

12.4.2. Strengthening the Role of International Organizations

International organizations such as the Food and Agriculture Organization (FAO) and the World Organization for Animal Health (OIE) play critical roles in preventing the spread of livestock epidemics. These organizations should support countries in sharing biosecurity data and adhering to international biosecurity standards. Additionally, it is necessary to establish policies that ensure interoperability and interconnectedness of biosecurity systems worldwide.

12.5. Biosecurity Systems for Sustainable Livestock Farming

Digitized livestock biosecurity systems can play a significant role in the sustainable development of the livestock industry. It is crucial to reduce large-scale culling or the use of chemical agents while enhancing animal welfare. Achieving this requires policy support for establishing sustainable biosecurity systems.

12.5.1. Establishing Sustainable Biosecurity Systems

The government should adopt smart biosecurity systems that minimize environmental impacts, such as large-scale culling, while improving animal welfare. This approach will help prevent the spread of epidemics while ensuring environmental sustainability. Importantly, introducing environmentally friendly biosecurity methods and nature-friendly technologies is essential to reducing the negative impacts of livestock farming on the environment.

12.5.2. Promoting the Use of Eco-Friendly Biosecurity Resources

The government should promote the use of eco-friendly biosecurity resources through the introduction of smart biosecurity systems. It is important to selectively use biosecurity resources with IoT sensors and AI analysis systems while minimizing unnecessary chemical usage. This will enhance the environmental sustainability of the livestock industry and achieve both environmental protection and economic success in the long term.

13. Conclusion

Digitized livestock biosecurity systems have emerged as innovative tools in the prevention and response to livestock epidemics. By leveraging advanced technologies such as IoT, AI, big data, and blockchain to collect and analyze real-time data, these systems can effectively prevent the spread of epidemics and manage biosecurity resources efficiently. Such systems are regarded as essential technologies capable of overcoming the limitations of traditional biosecurity methods and shaping the future of global livestock farming.

Through the adoption of smart livestock biosecurity systems, it is possible to prevent the spread of epidemics in advance, reduce biosecurity costs, and enhance animal welfare. Furthermore, strengthening data sharing and interoperability of biosecurity systems through international cooperation is crucial for establishing a global biosecurity network.

The future biosecurity systems will continue to evolve through higher levels of technological innovation and international cooperation, fostering sustainable development of the livestock industry worldwide. Digitized biosecurity systems will play a vital role in addressing epidemic issues, ultimately enhancing the efficiency, economic viability, and environmental sustainability of livestock farming in the long run.

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