CONFERENCE BOOK

HATTUSAS 3. ULUSLARARASI UYGULAMALI BİLİMLER KONGRESİ

ÇORUM
13 - 15 ŞUBAT 2026

HATTUSAS
3. ULUSLARARASI UYGULAMALI BİLİMLER KONGRESİ

HATTUSAS 3rd INTERNATIONAL CONFERENCE ON APPLIED SCIENCES
FEBRUARY 13 – 15, 2026
CORUM

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HATTUSAS 3RD INTERNATIONAL CONFERENCE ON APPLIED SCIENCES
FEBRUARY 13 – 15, 2026
CORUM

Edited By
ASSOC. PROF. DR. ABBAS GHAFFARI

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ASSOCIATION & ACADEMIC INCENTIVES :
In the conference 18 papers have been presented by Turkish participants and 36 papers by international participants.
Members of the organizing committees of the conference perform their duties with an "official assignment letter"

Web: www.hattusaskongresi.org Contact: hattusaskongresi@gmail.com

CONFERENCE ID

HATTUSAS 3RD INTERNATIONAL CONFERENCE ON APPLIED SCIENCES

DATE – PLACE
FEBRUARY 13 – 15, 2026
CORUM

ORGANIIZATION
ACADEMY GLOBAL CONFERENCES & JOURNALS

EVALUATION PROCESS
All applications have undergone a double-blind peer review process.

PARTICIPATING COUNTRIES

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PRESENTATION
Oral presentation

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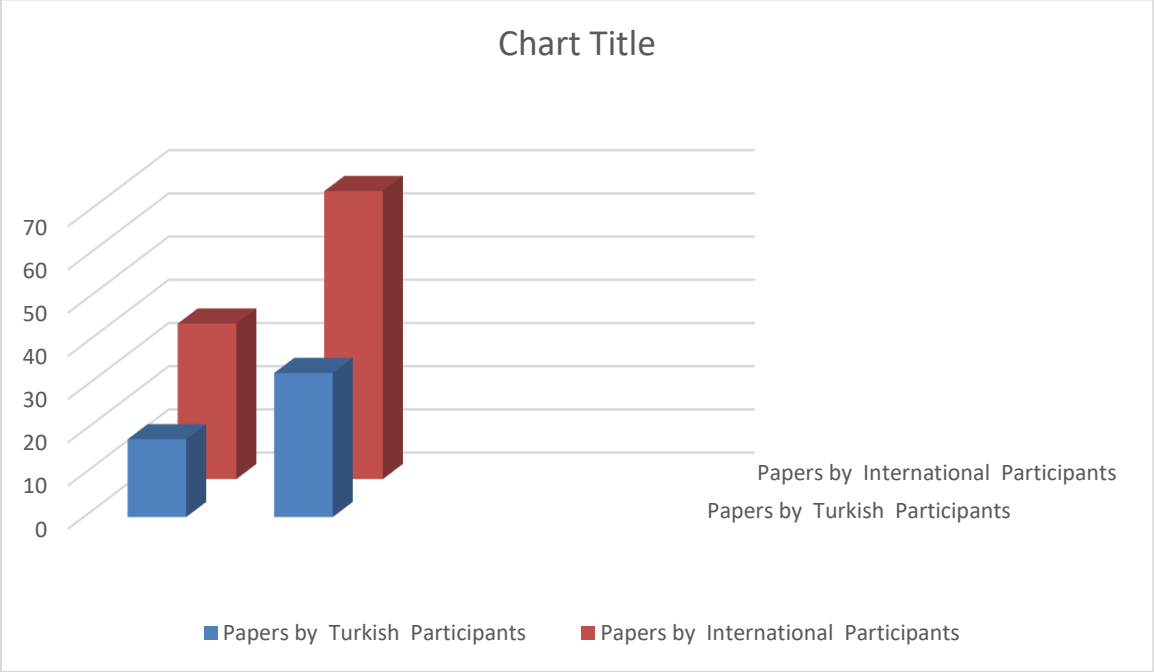
	Number of paper	*%*
Papers by Turkish Participants	18	33,33
Papers by International Participants (14 Countries)	36	66,66



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Veteriner Fakültesi Dekanlığı

Sayı : E-36643897-000-2300315795 05.10.2023
Konu : Görevlendirilme.

KLİNİK BİLİMLER BÖLÜMÜ BAŞKANLIĞINA

İlgi : 04.10.2023 tarihli ve E-36643897-000-2300313904 sayılı belge.

İlgide kayıtlı yazıda belirtildiği üzere, Bölümünüz Veterinerlik İç Hastalıkları Anabilim Dalı öğretim üyelerinden Prof. Dr. Başak HANEDAN'ın, "Academy Global Conferences & Publishing tarafından önümüzdeki tarihlerde düzenlenecek olan uluslararası kongrelerde; kongre başkanı, kongre düzenleme ve bilim kurulu üyesi olarak görevlendirilmesi Dekanlığımızca uygun görülmüştür.

Bilgilerinizi ve gereğini rica ederim.

Prof.Dr. Yavuz Selim SAĞLAM
Dekan

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HATTUSAS 3RD INTERNATIONAL CONFERENCE ON SOCIAL SCIENCES
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February 13 – 15, 2026
CORUM

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- Oturuma bağlanmadan önce Salon numaranızı adınızın önüne aşağıdaki gibi ekleyiniz. Bu sayede kongre açılışında beklemeden oturumlarınıza gönderilebileceksiniz. Ör. 5 Ahmet Ahmetoglu
- **Sunum süresi 10 dakikadır. Bu sürenin aşılmamasını moderatörler temin edecektir.**
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13 Şubat / Feb 13, 2026 / 11:00 – 13:00 Time zone in Turkey (GMT+3)				
Salon	Moderator		Bildiri No ve Başlığı / Paper ID and Title	Authors
HALL / SALON 2	**Dr.Öğr.Üyesi Özge Öz Yıldırım**	1	KAZANILMIŞ İMMÜN YETERSİZLİK SENDROMU (AIDS)	Prof. Dr. Yahya KUYUCUOĞLU Hemşire, Yüksek Lisans Öğrencisi, Esra Nur ÇARLI
		2	THE EFFECT OF STIGMATISATION ON URINARY INCONTINENCE SEVERITY AND FRAILTY IN OLDER ADULTS WITH URINARY INCONTINENCE: A MEDIATION MODEL	Dr.Öğr.Üyesi Özge Öz Yıldırım
		3	EFFECTS OF GAME-BASED DIGITAL REHABILITATION APPLICATIONS ON KINESIOPHOBIA, REHABILITATION COMPLIANCE, AND FUNCTIONAL INDEPENDENCE IN BURN REHABILITATION	Uzm.Fzt. DİLEK AYDİLEK ÖZDAŞ Öğr.Gör. ENES DİLMEN Doç.Dr. MAHMUT YARAN
		4	GAIT ABNORMALITIES IN TRANSTIBIAL PROSTHESIS USERS: A CURRENT REVIEW	Lecturer Enes Dilmen Specialist Physiotherapist Dilek Aydilek Özdaş Assoc. Prof. Mahmut Yaran
		5	A MACHINE LEARNING APPROACH FOR EARLY RISK PREDICTION OF SEPSIS-RELATED ACUTE RENAL INJURY IN INTENSIVE CARE PATIENTS	Kübranur KOCATÜRK Prof.Dr.Fatma LATİFOĞLU

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HALL / SALON 3	**Doç. Dr. Salih Berkan AYDEMİR**	1	YÖNETİM BİLİŞİM SİSTEMLERİ PERSPEKTİFİNDEN ÜRETKEN YAPAY ZEKÂ VE BÜYÜK DİL MODELLERİ: WOS TABANLI BİBLİYOMETRİK VE BERTOPİC EĞİLİM ANALİZİ	Dr. AHMET BÜYÜKEKE
		2	METAHEURISTIC OPTIMIZATION APPROACHES FOR IOT SENSOR PLACEMENT AND ENERGY-AWARE NETWORK ROUTING	Doç. Dr. Salih Berkan AYDEMİR
		3	A COMPARATIVE STUDY OF NATURE-INSPIRED METAHEURISTIC ALGORITHMS FOR SOLVING THE 0/1 KNAPSACK PROBLEM	Doç. Dr. Salih Berkan AYDEMİR
		4	STABILITY-VALUED NEUTROSOPHIC-POSITIVE DIRECTED SETS	Prof. Dr. İRFAN DELİ M.Sc. Student, MİHRİBAN DOĞRAMACIOĞLU
		5	ON STABILITY-VALUED NEUTROSOPHİC-NEGATIVE DIRECTED SETS AND ITS APPLICATIONS	Prof. Dr. İRFAN DELİ M.Sc. Student, MİHRİBAN DOĞRAMACIOĞLU
		6	GEARBOX FAULT DIAGNOSIS USING MULTI-SENSOR VIBRATION ANALYSIS AND LIGHT GRADIENT BOOSTING MACHINE	Dr. Öğr. Üyesi Emrah ASLAN Dr. Öğr. Üyesi Yıldırım ÖZÜPAK
		7	REMAINING USEFUL LIFE PREDICTION OF GEARBOX SYSTEMS USING A STACKING ENSEMBLE REGRESSION FRAMEWORK	Dr. Öğr. Üyesi Emrah ASLAN Dr. Öğr. Üyesi Yıldırım ÖZÜPAK

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HALL / SALON 4	**Doç.Dr Ahmed ALDYAB**	1	RAMADAN AND RELATED PRACTICES IN THE BOSNIAN SABİT DİVANI	Dr. Oğuz YILDIRIM
		2	AN EVALUATION OF ERZURUMLU EMRAH AND SELECTED POETRY EXAMPLES WITHIN THE CONTEXT OF FOLK AND COURT POETRY	Dr. Oğuz YILDIRIM
		3	AN ANALYSIS OF FRANZ KAFKA'S PENAL COLONIAL IN THE CONTEXT OF PUNISHMENT AND JUSTICE	Doç. Dr. SEVRA FIRINCIOĞULLARI
		4	TRANSLATION AND CULTURE	Doç.Dr Ahmed ALDYAB
		5	THE IMMERSIVE LANGUAGE APPROACH AND ITS ROLE IN DEVELOPING CONVERSATION SKILLS FOR NON-ARABIC SPEAKERS	Doç.Dr Ahmed ALDYAB
		6	BİRLİKTE YAŞAMA KÜLTÜRÜNÜN GÜNDELİK YAŞAMDA SÜRDÜRÜLMESİNDE KADINLARIN ROLÜ: GOFFMAN'IN DRAMATURJİK YAKLAŞIMI ÜZERİNDEN KURAMSAL BİR DEĞERLENDİRME	Yüksek Lisans Öğrencisi, Gamze Burak Prof. Dr., Ahmet Burak Kahraman
		7	THE PLACE OF THE GENERAL EDUCATION REGULATION IN THE FORMATION OF TODAY'S EDUCATIONAL LEVELS	Prof. Dr. Mehmet SAĞLAM
		8	TRANSFORMATION IN EDUCATION WITHIN THE FRAMEWORK OF THE NATION-STATE	Prof. Dr. Mehmet SAĞLAM

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HALL / SALON 5	**Dr. Nadia El-Sayed**	1	OPTIMAL TIMING FOR COLOSTRUM IMMUNOGLOBULIN ABSORPTION IN NEWBORN CAMELS: CORRELATION WITH CORTISOL AND THYROXIN LEVELS	Dr. Fatima Al-Mansouri Dr. Khaled Al-Harbi Dr. Youssef Benali
		2	DEVELOPMENTAL CHANGES IN THE DUODENAL MUCOSA AND SUBMUCOSA OF RABBITS	Dr. Nadia El-Sayed Dr. Omar Khalil
		3	EVALUATION OF TUBERCULIN, TETANUS IMMUNOGLOBULIN, AND DPT VACCINE AS MITOGENS IN AVIAN T-LYMPHOCYTE PROLIFERATION	Assoc. Prof. Dr. Samuel Okoro
		4	ASSESSMENT OF POTATO VARIETIES FOR CHIPS AND FRENCH FRIES PRODUCTION USING MICROWAVE-VACUUM DRYING TECHNOLOGY	Inga Jansons Kristaps Ozols Marta Kalnina Tatjana Ziedina
		5	SALT TOLERANCE IN TISSUE-CULTURED DATE PALM VARIETIES UNDER CONTROLLED ENVIRONMENTAL CONDITIONS	Dr. Hassan Al-Mulla Dr. Khalil Al-Farsi
		6	IMPACT OF COPPER AND ZINC DEFICIENCY ON MILK YIELD IN INTENSIVELY MANAGED DAIRY CATTLE: A STUDY FROM NORTHEASTERN ROMANIA	Dr. Elena Popescu Dr. Mihai Ionescu Dr. Carmen Georgescu
		7	EFFECTS OF OVERFEEDING ON PRODUCTIVITY, FOIE GRAS QUALITY, BLOOD PARAMETERS, AND MORTALITY IN TWO BREEDS OF DUCKS	Dr. Mona El-Sayed Dr. Ahmed Mahrous

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HALL / SALON 6	**Dr. Haruto Yamamoto**	1	IMPACT OF TRAINING INTENSITY ON PHYSICAL FITNESS PARAMETERS AMONG U-17 FEMALE BASKETBALL ATHLETES IN KENYA	Dr. Amina Mwangi Assis. Prof. Dr. Joseph Kamau
		2	THE IMPACT OF DAILY WALKING HABITS ON SLEEP QUALITY AMONG JAPANESE HIGH SCHOOL STUDENTS	Dr. Haruto Yamamoto
		3	ADVANCED PEDAGOGICAL APPROACHES TO IMPROVE BALANCE AND MOTOR SKILLS IN ADOLESCENTS	Lucia Fernández Mateo García
		4	ANALYZING THE INFLUENCE OF BODY ART ON ATHLETIC PERFORMANCE AND PSYCHOLOGICAL RESILIENCE	Dr. Moussa Traoré
		5	FROM TWEETS TO TOUCHDOWNS: FORECASTING NFL SUCCESS THROUGH SOCIAL MEDIA SENTIMENT ANALYSIS	Prof. Dr. Marcus Johnson Dr. Emily Carter
		6	SOUTH AFRICAN SOCCER DEVELOPMENT: ANALYZING LOCAL PRACTICES WITHIN A GLOBAL FRAMEWORK FOR MASS AND ELITE ATHLETE PROGRESSION	Dr. Thabo Mbeki Prof. Dr. Sipho Dlamini Dr. Naledi Khumalo
		7	ANALYSIS OF PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF ELITE KENYAN LONG-DISTANCE RUNNERS	Dr. Samuel Kiprotich Assoc. Prof. Dr. Grace Wanjiku
		8	EFFECTS OF WATER IMMERSION ON THERMOREGULATION AND RECOVERY IN ATHLETES TRAINING IN HIGH-TEMPERATURE ENVIRONMENTS	Ayesha Khan Imran Siddiqui Sara Malik

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HALL / SALON 7	**Jing Wei**	1	ANALYSIS OF PAYMENT DELAYS AND THEIR IMPACT ON THE CONSTRUCTION INDUSTRY IN MALAYSIA	Siti Nur Aisyah
		2	EVALUATING THE PROGRESS OF MANUFACTURING CONTROL SYSTEMS IN LIBYA'S INDUSTRIAL SECTOR	Muna Al-Faraj
		3	COMPARATIVE STUDY OF ENVIRONMENTAL REPORTING IN THE CHEMICAL INDUSTRY: GRI STANDARDS APPLICATION	Dr. Emily Thompson
		4	DESIGN AND BLAST RESISTANCE ANALYSIS OF SINGLE-STORY CONTROL FACILITIES IN PETROLEUM REFINERIES	Khaled Al-Mahdi Omar Farouk
		5	IMPACT OF BUSINESS MODEL INNOVATION ON CORPORATE VALUATION: A DYNAMIC FRAMEWORK	Wei Zhang Li Mei Jian Liu
		6	THE ROLE OF ALIGNMENT IN BOOSTING SERVICE INNOVATION PERFORMANCE: A NEW CONCEPTUAL MODEL	Chun-Hua Lin Mei-Ying Huang Yu-Fen Wu
		7	PROMOTING LOW-CARBON TRANSITION IN CHINA'S TRADITIONAL MANUFACTURING INDUSTRIES	Jing Wei

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HALL / SALON 8	**Dr. Ogunduyile O. Oluwgbenga**	1	ASSESSING THE QUALITY STANDARDS OF HOSPITAL PHARMACIES IN THERAPEUTIC CENTERS ASSOCIATED WITH KERMANSHAH UNIVERSITY OF MEDICAL SCIENCES, IRAN	Dr. Gharehbagh V.Hamishehkar , H.Aghababa
		2	OPTIMIZING VISIBLE LIGHT COMMUNICATION SYSTEMS THROUGH NATURAL LIGHT INTEGRATION	Mahmoud H. Aly, Ivan Andonovic, Moustafa Beshr
		3	INTEGRATING WIRELESS BODY AREA NETWORKS WITH WEB SERVICES: REVOLUTIONIZING UBIQUITOUS HEALTHCARE PROVISIONING THROUGH ARCHITECTURE	Dr. Ogunduyile O. Oluwgbenga
		4	DYNAMIC BRAIN WAVE ACQUISITION AND PSYCHOACOUSTIC ANALYSIS IN REAL TIME	Dipali SShweta , ingh Mahajan , Bansal Rashima
		5	ENHANCING COMBAT EFFECTIVENESS IN NEW GENERATION FIGHTER PLANES THROUGH HUMAN FACTORS CONSIDERATIONS	Binoy Bhargavan
		6	CONSTRUCTING AN INTEGRATED RELATIONAL DATABASE UTILIZING SWISS NUTRITION NATIONAL SURVEY AND HEALTH DATASETS FOR DATA MINING OBJECTIVES	Helena Einsele , Dr. Jenzer Farshideh
		7	CAN EEG TESTING AID IN BRAIN TUMOR IDENTIFICATION?	M. Sharanreddy, P. K. Kulkarni
		8	EXAMINING THE HAZARDS OF INADEQUATE MEDICAL WASTE MANAGEMENT PRACTICES ON HUMAN HEALTH AND THE ENVIRONMENT: A REVIEW OF LITERATURE	Babanyara Ibrahim, Garba Bogoro., M. Y.Abubakar,

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HALL / SALON 9	**Assoc. Prof. Dr. Emily Carter**	1	ANALYSIS OF SOIL STABILIZATION TECHNIQUES USING ORGANIC ADDITIVES IN SEMI-ARID REGIONS	Dr. Fatima Zahra Dr. Karim Benali Dr. Amina El-Mansouri
		2	CLOUD-BASED DEVELOPMENT FRAMEWORKS FOR ADVANCED CONSTRUCTION MANAGEMENT SOFTWARE	Assoc. Prof. Dr. Min-Jae Park
		3	NUMERICAL MODELING OF ELECTROMAGNETIC FIELDS IN COMPLEX MATERIALS USING FINITE ELEMENT ANALYSIS	Assoc. Prof. Dr. Carlos Mendoza Dr. Lucia Fernandez
		4	THERMAL PERFORMANCE EVALUATION OF ECO-FRIENDLY INSULATION MATERIALS IN WOODEN BUILDINGS	Dr. Lars Jensen Mette Sørensen
		5	MULTI-CRITERIA ANALYSIS OF SAFETY MANAGEMENT PRACTICES IN CONSTRUCTION PROJECTS	Wei Zhang Mei Lin
		6	STABILITY ENHANCEMENT OF FUNCTIONALLY GRADED COMPOSITE PIPES UNDER FLUID FLOW CONDITIONS	Nabil Haddad Leila Mansour
		7		

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HALL / SALON 1	**Doç. Dr. Hatice Işıl ALKAN**	1		
		2	INTEGRATION OF ARTIFICIAL INTELLIGENCE AND BLOCKCHAIN TECHNOLOGY INTO ACCOUNTING PROCESSES: A CONCEPTUAL OVERVIEW	Dr. Öğr. Üyesi BAHRİ OZAN YAMAN
		3	DİJİTAL DEVRİMİN DİJİTAL BAĞIMLILIK VE TÜKETİCİNİN SATIN ALMA DAVRANIŞLARI ÜZERİNDEKİ ETKİSİ	Dr. BERRİN ERGİN
		4	DEVLETİN GERİ DÖNÜŞÜ: KÜRESEL SİSTEMDE YENİ DEVLETÇİLİK	Dr. Öğr. Üyesi Nurettin BİLMEZ
		5	TR62 BÖLGESİNDE İŞGÜCÜ PİYASASINDA EŞİTSİZLİKLER VE KIRILGANLIKLAR	Doç. Dr. Hatice Işıl ALKAN
		6	THE EFFECT OF SPORT PARTICIPATION ON PRO-ENVIRONMENTAL BEHAVIOR AND ENVIRONMENTAL ATTITUDES	İsmet SEVAL Dr. Okan SARI Doç. Dr. Şakir TÜFEKÇİ
		7	DIGITAL LEADERSHIP AND DIGITAL TRANSFORMATION İN SPORTS MANAGEMENT: A REVIEW OF NEW MANAGEMENT APPROACHES	İsmet SEVAL Dr. Okan SARI Doç. Dr. Şakir TÜFEKÇİ

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HALL / SALON 2	**Prof. Dr. MEHMET ÖZBAŞ**	1	VIOLENCE IN SCHOOLS: UNLIMITED EGOISM AND SOCIAL DECAY	Prof. Dr. MEHMET ÖZBAŞ
		2	TURKISH EDUCATION SYSTEM AND CURRENT SITUATION	Prof. Dr. MEHMET ÖZBAŞ
		3	DISASTER AWARENESS AND PREPAREDNESS AMONG PRE-SERVICE TEACHERS İN TÜRKIYE: A SYSTEMATIC EVALUATION	İRFAN ÜNLÜ DOÇ DR. GÜLBİN ZEREN NALİNCİ
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KAZANILMIŞ İMMÜN YETERSİZLİK SENDROMU (AIDS)

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ÖZET

HIV (Human Immunodeficiency Virus)/AIDS (Acquired Immunodeficiency Syndrome), 1980'lerden bu yana küresel sağlık sistemini derinden etkileyen önemli bir halk sağlığı sorunu olarak varlığını sürdürmektedir. Bu enfeksiyon, bağışıklık sistemini zayıflatarak bireyleri fırsatçı enfeksiyonlar ve bazı kanser türlerine karşı savunmasız hale getirir. Dünya Sağlık Örgütü (DSÖ) verilerine göre, 2022 itibarıyla dünya genelinde yaklaşık 38 milyon kişi HIV ile yaşamaktadır. Türkiye'de HIV epidemiyolojisi, dünya geneline kıyasla daha düşük prevalansa sahip olmakla birlikte, son yıllarda artış göstermektedir.

HIV, insan bağışıklık sistemine zarar vererek AIDS'e yol açan bir virüs olup, kan, semen, vajinal sıvılar, rektal sıvılar ve anne sütü gibi vücut sıvıları yoluyla bulaşmaktadır. HIV'den korunmanın temelinde bilinçli davranışlar, koruyucu önlemler ve toplumsal farkındalık yatmaktadır. Bireysel korunma yöntemleri arasında kondom kullanımı, steril iğne kullanımı ve düzenli test yer alırken; toplumsal korunma stratejileri eğitim programları, damgalama ile mücadele ve sağlık hizmetlerine erişimin iyileştirilmesini kapsamaktadır.

AIDS hastalarına yönelik hemşirelik yaklaşımı, yalnızca fiziksel sağlık durumlarını değil, aynı zamanda psikososyal ihtiyaçlarını da göz önünde bulunduran bütüncül bir bakım anlayışını gerektirir. Hemşireler, HIV pozitif bireylerin tedavi sürecini yönetirken, hasta eğitimi, danışmanlık ve duygusal destek sağlama gibi önemli roller üstlenir. Ayrıca, HIV pozitif bireylerin mahremiyetine saygı göstermek, hasta bilgilerinin gizliliğini sağlamak ve ayrımcılık yapmamak, hemşirelerin temel etik görevlerindendir.

Sonuç olarak, AIDS ile mücadele yalnızca tıbbi müdahalelerle sınırlı kalmamalı, aynı zamanda toplumsal farkındalık, hasta destek mekanizmaları ve multidisipliner yaklaşımlar gibi birçok

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farklı boyutu kapsamalıdır. Hemşireler, bu mücadelede eğitici, destekleyici ve savunucu roller üstlenerek bireylerin sağlık ve refahını iyileştirme konusunda vazgeçilmez bir konumdadır.

Anahtar Kelimeler: HIV, AIDS, antiretroviral tedavi, hemşirelik bakımı, damgalama, korunma yöntemleri.

ABSTRACT

HIV (Human Immunodeficiency Virus)/AIDS (Acquired Immunodeficiency Syndrome) continues to exist as a significant public health problem that has deeply affected the global health system since the 1980s. This infection weakens the immune system, making individuals vulnerable to opportunistic infections and certain types of cancer. According to World Health Organization (WHO) data, approximately 38 million people worldwide were living with HIV as of 2022. In Turkey, the epidemiology of HIV has a lower prevalence compared to the world, but it has been increasing in recent years.

HIV is a virus that damages the human immune system and leads to AIDS, transmitted through body fluids such as blood, semen, vaginal fluids, rectal fluids, and breast milk. The basis of protection from HIV lies in conscious behaviors, protective measures, and societal awareness. Individual protection methods include condom use, sterile needle use, and regular testing; while societal protection strategies encompass education programs, combating stigma, and improving access to healthcare services.

The nursing approach to AIDS patients requires a holistic care understanding that considers not only their physical health condition but also their psychosocial needs. Nurses undertake important roles such as patient education, counseling, and providing emotional support while managing the treatment process of HIV-positive individuals. Additionally, respecting the privacy of HIV-positive individuals, ensuring the confidentiality of patient information, and avoiding discrimination are among the fundamental ethical duties of nurses.

In conclusion, the fight against AIDS should not be limited only to medical interventions but should also cover many different dimensions such as societal awareness, patient support mechanisms, and multidisciplinary approaches. Nurses, by undertaking educational, supportive, and advocacy roles in this struggle, are in an indispensable position in improving the health and well-being of individuals.

Keywords: HIV, AIDS, antiretroviral therapy, nursing care, stigma, prevention methods.

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THE EFFECT OF STIGMATISATION ON URINARY INCONTINENCE SEVERITY AND FRAILTY IN OLDER ADULTS WITH URINARY INCONTINENCE: A MEDIATION MODEL

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ÖZET

This study aimed to investigate the mediating role of internalised Stigmatisation in the relationship between urinary incontinence severity and frailty among older adults with urinary incontinence. This cross-sectional study, based on a quantitative research design, was conducted with 328 older adults. Data were collected using a demographic information form, the Edmonton Frailty Scale, the Incontinence Severity Index, and the Elderly Internalised Stigma Scale. Descriptive statistics, independent t-tests, one-way ANOVA, Pearson correlation, and Hayes' regression-based mediation analysis were used for data analysis. The mean age of the participants was 74.03 ± 6.88. Stress urinary incontinence was reported by 52.7% of the participants. A significant differences were found between educational level and both frailty and internalised stigma ($p< 0.05$). Internalised stigma played a significant mediating role in the association between urinary incontinence severity and frailty among the elderly ($p < 0.05$). A strong positive correlation was also observed between frailty and internalised stigma ($r = 0.62$, $p < 0.001$). It has been determined that internalised stigma plays a significant mediating role in the effect of urinary incontinence severity on the frailty of elderly individuals. It can be said that internalised stigma is an important psychosocial indicator in the relationship between urinary incontinence severity and frailty.

Key words: Internalised stigma, urinary incontinence, severity, frailty, older adults

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YANIK REHABİLİTASYONUNDA OYUN TABANLI DİJİTAL REHABİLİTASYON UYGULAMALARININ KİNEZYOFOBİ, REHABİLİTASYONA UYUM VE FONKSİYONEL BAĞIMSIZLIK ÜZERİNE ETKİLERİ

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ÖZET

Giriş: Yanık yaralanmaları; ağrı, eklem hareket kısıtlılığı, skar gelişimi ve psikososyal sorunlar yoluyla bireylerin günlük yaşam aktivitelerini ve yaşam kalitesini olumsuz etkileyen önemli bir sağlık sorunudur. Yanık tedavisindeki gelişmeler mortaliteyi azaltmış olsa da, rehabilitasyon sürecinde kinezyofobi, rehabilitasyona uyum sorunları ve fonksiyonel bağımsızlık kaybı karşılaşılan problemler arasında önemini korumaktadır. Bu bağlamda, rehabilitasyon sürecini daha motive edici ve tolere edilebilir hâle getirmeyi amaçlayan oyun tabanlı dijital rehabilitasyon uygulamaları giderek daha fazla ilgi görmektedir. **Amaç:** Bu derlemenin amacı, yanık rehabilitasyonunda kullanılan oyun tabanlı dijital rehabilitasyon uygulamalarının kinezyofobi, rehabilitasyona uyum ve fonksiyonel bağımsızlık üzerindeki etkilerini inceleyen güncel literatürü değerlendirmektir. **Yöntem:** Bu anlatı derlemede PubMed, Scopus, Web of Science ve Google Scholar veri tabanları taranmıştır. 2020–2025 yılları arasında yayımlanan sistematik derlemeler, randomize kontrollü çalışmalar ve klinik araştırmalar değerlendirmeye alınmıştır. **Bulgular:** Yanık rehabilitasyonunda oyun tabanlı dijital uygulamaların ağrı algısını azaltarak hareketle ilişkili korku ve kaçınma davranışlarını sınırlayabildiğini göstermektedir. Ayrıca söz konusu uygulamaların, motivasyonu artırarak rehabilitasyona uyumu desteklediği ve egzersize katılımı artırdığı bildirilmektedir. Artan rehabilitasyon uyumunun; eklem hareket açıklığı, kas gücü ve fonksiyonel mobilite gibi parametreler üzerinden fonksiyonel bağımsızlığın gelişimine dolaylı katkı sağladığı belirtilmektedir. Sanal gerçeklik ve exergame tabanlı yaklaşımlar, dikkat dağıtma ve oyunlaştırma mekanizmalarıyla etkinlik sağlamaktadır. **Sonuç:** Oyun tabanlı dijital rehabilitasyon uygulamaları, yanık rehabilitasyonunda kinezyofobinin azaltılması, rehabilitasyona uyumun artırılması ve fonksiyonel bağımsızlığın desteklenmesi açısından olumlu etkilere sahiptir. Ancak bu uygulamaların klinik etkinliğini ve uzun dönemli fonksiyonel sonuçlarını ortaya koymak için daha fazla yüksek metodolojik kalitede çalışmaya ihtiyaç vardır.

Anahtar Kelimeler: Yanık Rehabilitasyonu, Oyun Tabanlı Dijital Rehabilitasyon, Kinezyofobi, Rehabilitasyona Uyum, Fonksiyonel Bağımsızlık

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EFFECTS OF GAME-BASED DIGITAL REHABILITATION APPLICATIONS ON KINESIOPHOBIA, REHABILITATION COMPLIANCE, AND FUNCTIONAL INDEPENDENCE IN BURN REHABILITATION

ABSTRACT

Introduction: Burn injuries are a significant health problem that negatively affects individuals' daily activities and quality of life through pain, joint movement restrictions, scar development, and psychosocial issues. Although advances in burn treatment have reduced mortality, kinesiophobia, rehabilitation compliance issues, and loss of functional independence remain significant problems encountered during the rehabilitation process. In this context, game-based digital rehabilitation applications, which aim to make the rehabilitation process more motivating and tolerable, are gaining increasing attention. **Objective:** The aim of this review is to evaluate the current literature examining the effects of game-based digital rehabilitation applications used in burn rehabilitation on kinesiophobia, rehabilitation compliance, and functional independence. **Method:** The PubMed, Scopus, Web of Science, and Google Scholar databases were searched for this narrative review. Systematic reviews, randomised controlled trials, and clinical studies published between 2020 and 2025 were included in the evaluation. **Findings:** Game-based digital applications in burn rehabilitation have been shown to reduce pain perception, thereby limiting movement-related fear and avoidance behaviours. Furthermore, it is reported that these applications support rehabilitation compliance by increasing motivation and enhancing exercise participation. Increased rehabilitation compliance is noted to indirectly contribute to the development of functional independence through parameters such as joint range of motion, muscle strength, and functional mobility. Virtual reality and exergame-based approaches provide effectiveness through distraction and gamification mechanisms. **Conclusion:** Game-based digital rehabilitation applications have positive effects in burn rehabilitation in terms of reducing kinesiophobia, increasing rehabilitation compliance, and supporting functional independence. However, more studies of high methodological quality are needed to demonstrate the clinical efficacy and long-term functional outcomes of these applications.

Keywords: Burn Rehabilitation, Game-based Digital Rehabilitation, Kinesiophobia, Rehabilitation Compliance, Functional Independence

GİRİŞ

Yanık yaralanmaları, derinin yüksek sıcaklık, sürtünme, elektrik, radyasyon veya kimyasal maddelere maruz kalması sonucunda oluşan ve her yıl yaklaşık 180.000 ölüme neden olan küresel bir halk sağlığı sorunu olarak tanımlanmaktadır (WHO, 2025; Zwierełło et al.,2023). Yanık tedavisindeki gelişmeler sayesinde mortalite oranları azalmış; ancak rehabilitasyona ihtiyaç duyan bireylerin sayısında artış meydana gelmiştir (Santos, 2025). Yanık yaralanmaları yalnızca doku bütünlüğünü etkilemekle kalmamakta; ağrı, hareket kısıtlılığı ve skar oluşumu gibi fizyolojik sorunların yanı sıra, bireylerin günlük yaşam aktivitelerini ve yaşam kalitesini olumsuz etkileyen psikososyal sorunlara da yol açmaktadır (Petrou et al, 2025). Yanık yaralanmalarında el, dirsek ve omuz eklemleri en sık etkilenen eklemler arasında yer almakta olup, ciddi yanık vakalarında taburculuk sırasında eklem disfonksiyonu prevalansının %22–42 arasında olduğu bildirilmektedir (Lan et al, 2023). Bu oranlar, yanık tedavisinde rehabilitasyonun rolüne dikkat çekmektedir.

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Hareket ve yeniden yaralanma korkusu olarak tanımlanan kinezyofobi, yanık vakalarında sıklıkla karşılaşılan ancak literatürde görece sınırlı ele alınmış bir konudur. Kinezyofobisi olan bireylerin rehabilitasyon sürecinden kaçındığı ve yeterli düzeyde egzersiz yapmadığı bildirilmiştir (Jeong et al., 2022). Çalışmalar, yanık hastalarının fizyoterapiyi tedavi sürecinin ağrılı bir bileşeni olarak algıladığını ortaya koymaktadır. Hareketle ilişkili ağrı, kaygı ve korku, oluşturulan rehabilitasyon programına katılımı olumsuz yönde etkilemektedir (Basha et al., 2022; Sean et al., 2023). Ayrıca yanık rehabilitasyonunda uzun süreli ve tekrarlayan egzersizlerin gerekli olması, tedavi sürecinin monoton algılanmasına yol açabilmekte; bu durum düzenli egzersiz alışkanlığının sürdürülmesini güçleştirebilmektedir (Bressler et al., 2024).

Bu bağlamda, yanık rehabilitasyonunda kinezyofobiye bağlı kaçınma davranışlarını azaltmak ve rehabilitasyona uyumu artırmak amacıyla teknoloji destekli rehabilitasyon yaklaşımlarına olan ilgi giderek artmaktadır. Bu derlemede "oyun tabanlı dijital rehabilitasyon" kavramı, sanal gerçeklik tabanlı ve sanal gerçeklik dışı exergame uygulamalarını kapsayan üst bir yaklaşım olarak ele alınmıştır. Sanal gerçeklik ve exergame tabanlı uygulamalar, egzersizi daha etkileşimli ve motive edici hale getirerek algılanan ağrı ve hareket korkusunu azaltma potansiyeli taşımaktadır. Güncel çalışmalar, bu teknolojik yaklaşımların yanık hastalarında ağrı ve kaygıyı azalttığını, fonksiyonel kazanımları desteklediğini ve rehabilitasyona uyumu artırdığını ortaya koymaktadır (Lan et al., 2023; Santos et al., 2025). Bu çalışmanın amacı, yanık rehabilitasyonunda kinezyofobinin klinik ve fonksiyonel etkilerini inceleyen güncel literatürü derlemek ve teknoloji destekli yaklaşımların rehabilitasyona uyum üzerindeki etkilerini literatür ışığında bütüncül bir bakış açısıyla ortaya koymaktır.

YÖNTEM

Bu çalışma, yanık rehabilitasyonunda kinezyofobi, rehabilitasyona uyum ve fonksiyonel bağımsızlık üzerine güncel literatürün derlenmesi ve oyun tabanlı dijital rehabilitasyon uygulamalarının bu değişkenler üzerine etkisinin incelenmesi amacıyla anlatı türde bir literatür derlemesidir. Literatür taraması yapılırken PubMed, Scopus, Web of Science ve Google Scholar veri tabanları kullanılmıştır. Tarama sürecinde İngilizce anahtar kelimeler kullanılmıştır. "Burn rehabilitation", "kinesiophobia", "fear of movement", "rehabilitation adherence", "exercise adherence", "functional independence", "virtual reality", "exergame" ve "technology-assisted rehabilitation" kullanılan başlıca anahtar kelimelerdir. Derlemeye 2020-2025 yılları arasında yayınlanan yanık rehabilitasyonunda kinezyofobi, rehabilitasyona uyum ve fonksiyonel bağımsızlık ile ilişkilendirilen sistemik derlemeler, meta-analizler, randomize kontrollü çalışmalar dahil edilmiştir. Olgu sunumları ve yanık rehabilitasyonunu doğrudan içermeyen çalışmalar dışlanmıştır.

BULGULAR

Oyun Tabanlı Dijital Rehabilitasyon Uygulamalarının Kinezyofobi Üzerine Etkileri: Korku- kaçınma davranışı ilk olarak bel ağrısı yaşayan bireylerde tanımlanmış olmakla birlikte (Lethem et al., 1983), daha sonraki çalışmalarda çeşitli kas-iskelet sistemi rahatsızlıklarında da görülen bir semptom olarak literatürde yer almıştır. Hareket ve yeniden yaralanma korkusu olan kinezyofobi, yanık hastalarında da rehabilitasyonu olumsuz etkileyen önemli bir psikolojik faktör olarak bildirilmektedir. Yanık yaralanması sonrasında hem akut hem de rehabilitasyon sürecinde deneyimlenen yoğun ağrının, kinezyofobinin gelişimine neden olduğu bildirilmektedir (Langlois et al., 2021).

Literatürde yanık rehabilitasyonunda kullanılan oyun temelli dijital rehabilitasyon uygulamalarının, hareketle ilişkili korku ve kaygı düzeylerinde olumlu etkiler oluşturabildiğine

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işaret edilmektedir. Özellikle sanal gerçeklik uygulamalarının, kullanıcıyı interaktif, çok duyulu bir bilgisayar ortamına daldırarak kapı kontrol teorisi doğrultusunda ağrı sinyallerinin bilinçli farkındalığa ulaşmasını azalttığı belirtilmektedir (Sean et al., 2023).

Oyunlaştırılmış egzersizler aracılığıyla hastaların ağrılı hareket açıklığı aktivitelerine katılımının artırılması, hareketle ilişkili korkunun azaltılmasına katkı sağlamakta ve dolaylı olarak kinezyofobi üzerinde olumlu etkiler oluşturmaktadır. Çalışmalar, oyun temelli dijital rehabilitasyon uygulamalarının kullanıldığı yanık hastalarında hareketten kaçınma davranışlarının azaldığı ve egzersize katılımın arttığını göstermektedir. Bu yaklaşımların, geleneksel rehabilitasyon yöntemlerine kıyasla hastaların tedavi sürecine daha istekli katılım sağladığı ve kinezyofobiyle ilişkili olumsuz davranışları azalttığı rapor edilmiştir (Yang et al., 2025).

Oyun Tabanlı Dijital Rehabilitasyon Uygulamalarının Rehabilitasyona Uyum Üzerine Etkileri: Yanık yaralanması sonrası eklem disfonksiyonun önlenmesi, rehabilitasyon başarısında belirleyici bir faktör olarak kabul edilmektedir. Yanık tedavisi, tekrarlı aktif ve pasif egzersizleri içeren, yoğun rehabilitasyon programı gerektiren uzun ve zorlu bir süreçtir. Geleneksel rehabilitasyon programlarında hastaların tedaviye katılımını zorlaştıran temel faktörlerden birinin, egzersizler sırasında deneyimlenen ağrı olduğu bildirilmektedir. Ağrıya bağlı bu durumun, rehabilitasyon sürecine katılımı ve tedaviye uyumu olumsuz etkilediği ifade edilmektedir (Lan et al., 2023).

Bu bağlamda, rehabilitasyon sürecini daha tolere edilebilir ve motive edici hâle getirmeyi amaçlayan teknoloji destekli rehabilitasyon programları son yıllarda öne çıkmaktadır. Eğlenceli ve ilgi çekici yapıları sayesinde bu uygulamaların, yanık hastalarının dikkatini ağrıdan uzaklaştırarak ağrı algısını azalttığı bildirilmektedir. Bu durumun, hastaların rehabilitasyon sürecine katılımını ve tedaviye uyumunu olumlu yönde etkilediği ifade edilmektedir. Ayrıca teknoloji destekli rehabilitasyon yaklaşımlarının, erişim kolaylığı sağlaması sayesinde kırsal bölgelerde yaşayan bireylerin rehabilitasyon hizmetlerine ulaşmasını kolaylaştırdığı belirtilmektedir (Atiaa et al., 2025).

Oyun Tabanlı Dijital Rehabilitasyon Uygulamalarının Fonksiyonel Bağımsızlık Üzerine Etkileri: Fonksiyonel bağımsızlık, yanık rehabilitasyon sürecinin temel hedeflerinden biri olup bireylerin kendi bakımlarını gerçekleştirebilme ve anlamlı aktiviteler yapabilme düzeyini ifade etmektedir (Jawad, 2024). Rehabilitasyon sürecinde eklem hareket açıklığının artması, ağrı düzeyinin azalması, üst ekstremite kavrama kuvveti ve kas gücündeki artış gibi klinik parametrelerin, fonksiyonel bağımsızlığın sağlanmasında önemli rol oynadığı bildirilmektedir (Lan et al., 2023; Joo et al.,2020).

Yapılan sistematik incelemeler, sanal gerçeklik tabanlı uygulamaların eklem hareket açıklığını artırabildiğini ve öz bakım ile fonksiyonel bağımsızlık düzeylerini geliştirebildiğini ortaya koymaktadır. Bununla birlikte, mevcut literatürde özellikle öz bakım ve hareketlilik alanlarında orta düzeyde kanıt bulunduğu ve daha yüksek metodolojik kalitede çalışmalara ihtiyaç olduğu vurgulanmaktadır (Riaz et al., 2025). Benzer şekilde exergame tabanlı uygulamalarında, fonksiyonel iyileşme ve bağımsızlık üzerinde etkili olabileceği bildirilmektedir (Santos et al., 2025).

TARTIŞMA

Bu derlemede, yanık rehabilitasyonunda oyun tabanlı dijital rehabilitasyon uygulamalarının kinezyofobi, rehabilitasyona uyum ve fonksiyonel bağımsızlık üzerindeki etkileri ele alınmıştır. Elde edilen bulgular, bu uygulamaların yanık hastalarında hareketle

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ilişkili korku ve kaygıyı azaltabildiğini, rehabilitasyon sürecine katılımı artırabildiğini ve fonksiyonel iyileşmeyi destekleyebildiğini göstermektedir.

Literatürde yanık mağdurlarında kinezyofobi davranışlarını doğrudan inceleyen çalışma sayısı sınırlıdır. Yanık rehabilitasyonunda deneyimlenen yoğun ve tekrarlayıcı ağrının, bireylerde hareketle ilişkili korkunun gelişmesine ve zamanla kaçınma davranışlarının ortaya çıkmasına neden olduğu bildirilmektedir. Hareketten kaçınma davranışları, yanık hastalarında eklem hareket açıklığının korunmasını zorlaştırmakta ve fonksiyonel iyileşme sürecini olumsuz etkilemektedir (Lu et al., 2025).

Bu derlemede incelenen çalışmalar, oyun tabanlı dijital rehabilitasyon uygulamalarının dikkat dağıtma ve oyunlaştırma yoluyla ağrı algısını azaltarak, hareketle ilişkili korkunun şiddetinin azalmasına katkı sağlayabildiğini düşündürmektedir. Özellikle sanal gerçeklik ve oyun tabanlı uygulamaların çok duyulu ve etkileşimli yapısının, kapı kontrol teorisi doğrultusunda ağrı uyaranlarının merkezi sinir sistemine iletimini azaltarak bireylerin hareket sırasında yaşadıkları korkunun azalmasına katkı sağlayabileceği ifade edilmektedir (Sean et al., 2023).

Rehabilitasyon sürecinde hastanın aktif ve istekli katılımı, tedavi başarısını doğrudan etkileyen temel faktörler arasında yer almaktadır. Yanık rehabilitasyonunda geleneksel yaklaşımlar, çoğunlukla tekrarlayıcı eklem hareketlerini içeren egzersiz programlarına dayanmaktadır. Ancak bu süreçte deneyimlenen ağrı, bireylerde hareketle ilişkili korkunun gelişmesine yol açarak kinezyofobiye neden olmakta ve tedaviye katılımı olumsuz yönde etkileyebilmektedir (Ramage et al., 2025).

Bu bağlamda, dijital tabanlı rehabilitasyon uygulamalarının eğlenceli ve ilgi çekici yapısı sayesinde ağrı algısını azalttığı, seans süresini uzattığı ve hastaların rehabilitasyon sürecini daha tolere edilebilir algılamalarına katkı sağladığı düşünülmektedir (Sibbett et al., 2025). Dijital yaklaşımların bu özelliklerinin, geleneksel rehabilitasyon programlarına kıyasla hastaların tedaviye katılımını ve sürece devamlılığını artırdığı ileri sürülebilir. Rehabilitasyona uyumdaki bu artışın egzersiz yoğunluğu ve sürekliliğini destekleyerek fonksiyonel kazanımların günlük yaşam aktivitelerine yansımasını kolaylaştırabileceği düşünülmektedir.

Fonksiyonel bağımsızlık, yanık rehabilitasyonunun temel hedeflerinden biri olup bireylerin öz bakım, mobilite ve günlük yaşam aktivitelerini gerçekleştirme düzeyini ifade etmektedir. Yanık sonrası gelişen eklem hareket kısıtlılığı, ağrı, kas gücü kaybı ve üst ekstremite fonksiyonlarındaki bozulmalar, fonksiyonel bağımsızlığın kazanılmasını doğrudan sınırlayan faktörler arasında yer almaktadır (Varzeshi et al., 2025).

Bu derlemede incelenen çalışmalar, rehabilitasyona uyumun artmasının fonksiyonel bağımsızlık üzerinde dolaylı ancak belirleyici bir etkiye sahip olduğunu düşündürmektedir. Özellikle düzenli egzersiz katılımının sağlanması, eklem hareket açıklığının korunması ve kas kuvvetinin artırılması yoluyla fonksiyonel kazanımların desteklenmesine katkı sağlamaktadır. Literatürde, rehabilitasyon sürecine aktif katılım gösteren yanık hastalarında öz bakım aktiviteleri ve fonksiyonel mobilite düzeylerinin daha hızlı iyileştiği bildirilmektedir (Garrido-Ardila et al., 2022).

Oyun tabanlı dijital rehabilitasyon uygulamalarının, ağrı algısını azaltma ve motivasyonu artırma yoluyla egzersize katılımı destekleyerek fonksiyonel bağımsızlığın gelişimine katkı sağlayabildiği literatürde vurgulanmaktadır.

SONUÇ

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Sonuç olarak; yanık rehabilitasyonunda oyun tabanlı dijital rehabilitasyon uygulamalarının kinezyofobiyi azaltarak rehabilitasyona uyumu kolaylaştırmaktadır. Rehabilitasyona uyumun artması, tedavi sürecini olumlu yönde etkileyerek fonksiyonel bağımsızlık üzerinde iyileştirici etkiye sahiptir. Ancak yanık rehabilitasyonunda oyun tabanlı dijital uygulamalarının kinezyofobi, rehabilitasyona uyum ve fonksiyonel bağımsızlık üzerindeki etkilerini inceleyen çalışma sayısının sınırlı olduğu dikkat çekmektedir. Bu sebeple gelecekte yapılacak çalışmaların, bu teknolojik yaklaşımların klinik etkinliğinin belirlenmesinde fayda sağlaması beklenmektedir. Ayrıca geleneksel rehabilitasyon programına entegre edilmesinin, hastaların tedaviye düzenli katılımını destekleyerek egzersiz alışkanlığı geliştirmesine katkı sağlayabileceği düşünülmektedir.

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DİZ ALTI PROTEZ KULLANICILARINDA YÜRÜYÜŞ BOZUKLUKLARI: GÜNCEL BİR DERLEME

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ÖZET

Diz altı amputasyon cerrahisi sonrası protezle yürüme; protez tarafta itme kuvvetinin sınırlı olması, güdükte yük toleransının zayıf olması ve güdük soket arayüzünde oluşan bileşke kuvvetler nedeniyle sıklıkla asimetrik bir paternle gerçekleşir. Bu durum spatiotemporal farklılıklar, proksimal eklemlerde kompansasyonlar ve artmış fizyolojik yük ile ilişkilidir. Bu derlemenin amacı, diz altı protez kullanıcılarında yürüyüş bozukluklarını güncel kanıt üzerinden özetlemek ve klinik uygulamaya yönelik çıkarımlar sunmaktır. Anlatı derleme yaklaşımıyla PubMed, Scopus, Web of Science ve Google Scholar veri tabanları 2015-2025 yılları arası için taranmış; sistematik derlemeler ve yürüyüş analizi çıktıları raporlayan primer çalışmalar değerlendirilmiştir. Literatür, birçok çalışmada yürüme hızının azalabildiğini; adım uzunluğu, duruş fazı süresi ve yer reaksiyon kuvveti dağılımında taraflar arası farklılıklar görülebildiğini göstermektedir. Sağlam ekstremitede diz ve kalça eklemlerine binen yüklerin artması yaygındır. Doğrudan veya dolaylı olarak pelvis ve kalça odaklı kompansatuvar stratejiler ise çok sık görülür. Enerji tüketiminin genellikle daha yüksek olduğu bir çok çalışmada ortaya koyulmaktadır. Protez ayak bileşeninin sertlik ve esneklik gibi özellikleri ile birlikte hizalamanın, süspansiyon sisteminin, soket teknolojilerinin, süspansiyon sitemleri ile soket teknolojilerinin uyumunun; biyomekanik çıktıları anlamlı biçimde etkileyebileceği bildirilmektedir. Sonuç olarak yürüyüş bozuklukları çok boyutludur; komponent seçimi ve uygun ayarlama ile hedefli rehabilitasyonun birlikte planlanması, asimetriyi ve aşırı eklem yüklerini azaltma potansiyeli taşır. Standartlaştırılmış protokollere dayanan ve uzun dönem klinik sonlanımları değerlendiren yüksek metodolojik kalitede çalışmalara gereksinim devam etmektedir.

Anahtar Kelimeler: diz altı protez, yürüyüş analizi, yürüyüş asimetrisi, biyomekanik, enerji maliyeti.

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GAIT ABNORMALITIES IN TRANSTIBIAL PROSTHESIS USERS: A CURRENT REVIEW

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ABSTRACT

Prosthetic ambulation following transtibial amputation is frequently characterized by gait asymmetry due to limited push-off capacity on the prosthetic side, reduced load tolerance of the residual limb, and resultant interface forces at the socket–residual limb junction. These alterations are commonly associated with spatiotemporal deviations, proximal joint compensations, and increased physiological demand. The aim of this narrative review was to summarise current evidence on gait abnormalities in transtibial prosthesis users and to present clinically relevant implications. PubMed, Scopus, Web of Science, and Google Scholar were searched for studies published between 2015 and 2025. Systematic reviews and primary studies reporting quantitative gait analysis outcomes were included. The literature indicates that walking speed may be reduced in this population, with interlimb differences observed in step length, stance phase duration, and ground reaction force distribution. Increased mechanical loading at the knee and hip joints of the intact limb is frequently reported, alongside pelvis- and hip-centred compensatory strategies. Numerous studies also demonstrate elevated energy expenditure compared with non-amputee controls. Prosthetic foot characteristics, such as stiffness and flexibility, as well as alignment, suspension systems, and socket technologies, have been shown to significantly influence biomechanical outcomes. In conclusion, gait abnormalities in transtibial prosthesis users are multidimensional; the integration of appropriate component selection, optimal fitting, and targeted rehabilitation strategies holds potential for reducing gait asymmetry and excessive joint loading. Further high-quality studies employing standardised protocols and assessing long-term clinical outcomes are warranted.

Keywords: transtibial prosthesis, gait analysis, gait asymmetry, biomechanics, energy expenditure

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Yoğun Bakım Hastalarında Sepsis İlişkili Akut Böbrek Hasarının Erken Risk Tahmini için Makine Öğrenimi Yaklaşımı

A Machine Learning Approach for Early Risk Prediction of Sepsis-Related Acute Renal Injury in Intensive Care Patients

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ÖZET

Sepsis, yüksek mortalite ile seyreden kritik bir klinik sendrom olup sepsisli hastalarda sepsis ilişkili akut böbrek hasarı (SA-AKI) gelişimi yoğun bakım mortalitesini belirgin şekilde artırmaktadır. SA-AKI insidansı dünya genelinde %30–40, Türkiye'de ise %25–45 aralığında bildirilmektedir. Bu nedenle hastalığın erken dönemde öngörülmesi, zamanında müdahale ve prognozun iyileştirilmesi açısından klinik önem taşımaktadır.

Bu çalışmada, yoğun bakım hastalarına ait çok değişkenli elektronik sağlık kayıtları (31 klinik özellik) kullanılarak SA-AKI'nin erken tahmini için makine öğrenimi tabanlı bir risk sınıflandırma modeli geliştirilmiştir. Veri ön işleme aşamasında eksik veri yönetimi, z-skor normalizasyonu ve sınıf dengesizliği için ADASYN uygulanmış; LASSO, ki-kare ve bilgi kazanımı temelli yöntemlerle özellik seçimi gerçekleştirilmiştir.Model performansı, veri seti üzerinde uygulanan 5 katlı çapraz doğrulama (k-fold cross validation) yöntemi ile değerlendirilmiştir.

Sonuçlar, özellikle XGBoost modelinin en yüksek performansı sağladığını (Accuracy=0.97, AUC=0.98) ve SA-AKI gelişimini güvenilir biçimde öngörebildiğini göstermiştir. Elde edilen Sonuçlar, EHR tabanlı makine öğrenimi yaklaşımlarının klinik karar destek sistemlerine entegre edilebilecek etkili ve uygulanabilir araçlar sunduğunu ortaya koymaktadır.

Anahtar Kelimeler — *Kronik böbrek hastalığı, Makine öğrenmesi, Sınıflandırma, Klinik karar desteği.*

ABSTRACT

Sepsis is a critical clinical syndrome characterized by high mortality, and the development of sepsis-associated acute kidney injury (SA-AKI) in septic patients significantly increases intensive care mortality. The incidence of SA-AKI is reported to be 30–40% worldwide and 25–45% in Turkey. Therefore, early prediction of the disease holds clinical importance in terms of timely intervention and improving prognosis.

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In this study, a machine learning-based risk classification model was developed for the early prediction of SA-AKI using multivariate electronic health records (31 clinical features) from intensive care patients. During the data preprocessing stage, missing data management, z-score normalization, and ADASYN for class imbalance were applied; feature selection was performed using LASSO, chi-square, and information gain-based methods.The model performance was evaluated by the 5-fold cross validation (k-fold cross validation) method applied on the data set.

The results showed that the XGBoost model provided the highest performance (Accuracy=0.97, AUC=0.98) and could reliably predict the development of SA-AKI. The findings reveal that EHR-based machine learning approaches offer effective and applicable tools that can be integrated into clinical decision support systems.

Key Words — *Chronic kidney disease, Machine learning, Classification, Clinical decision support.*

1. GİRİŞ

Sepsis ilişkili akut böbrek hasarı (SA-AKI), yoğun bakım hastalarında sık görülen ve mortaliteyi belirgin şekilde artıran ciddi bir klinik komplikasyondur (Koyner et al., 2018). Sistemik inflamasyon, mikrosirkülasyon bozuklukları ve hemodinamik dengesizlikler sonucunda gelişen bu tablo, saatler ila günler içinde hızlı böbrek fonksiyon kaybına yol açabilmekte ve erken tanı ile risk sınıflandırmasını kritik hale getirmektedir (Vagliano et al., 2022). Sepsis, enfeksiyona karşı gelişen kontrolsüz immün yanıt sonucu organ disfonksiyonu ile karakterize yaşamı tehdit eden bir sendromdur. Sepsis ile birlikte ortaya çıkan akut böbrek hasarı, patofizyolojisinde inflamasyon, endotel disfonksiyonu, mitokondriyal hasar ve hücresel ölüm mekanizmalarının rol oynadığı karmaşık bir süreçtir (Song et al., 2021). SA-AKI gelişen hastalarda mortalite oranları yalnızca sepsis veya yalnızca AKI görülen hastalara kıyasla anlamlı derecede daha yüksektir ve sağ kalan bireylerde uzun dönemde kronik böbrek hastalığı gelişme riski artmaktadır. Küresel ölçekte yılda yaklaşık 48,9 milyon sepsis vakası bildirilmekte olup, SA-AKI insidansı hasta popülasyonuna bağlı olarak %14–87 arasında değişmektedir. Yıllık 6–10 milyon kişinin SA-AKI geçirdiği tahmin edilmekte ve çok merkezli çalışmalarda yoğun bakım hastalarının yaklaşık %18'inde SA-AKI geliştiği belirtilmiştir (Khwaja, 2012). Türkiye'de ise yoğun bakım sepsis hastalarında AKI gelişme oranı %47'nin üzerine çıkmakta ve bu durum ulusal sağlık sistemi için önemli bir klinik yük oluşturmaktadır. Yoğun bakım ortamında üretilen elektronik sağlık kayıtları (EHR), çok boyutlu, heterojen ve zamana bağlı yapıları nedeniyle geleneksel istatistiksel yöntemlerle yeterince analiz edilememektedir. Makine öğrenimi algoritmaları ise karmaşık ve doğrusal olmayan ilişkileri modelleyebilme yetenekleri sayesinde erken risk öngörüsü ve klinik karar desteği açısından önemli avantajlar sunmaktadır. Bu kapsamda, yoğun bakım hastalarına ait büyük ölçekli elektronik sağlık kayıtlarını içeren açık erişimli veri tabanları (örneğin MIMIC-IV gibi) son yıllarda makine öğrenimi tabanlı prognostik model geliştirme çalışmalarında yaygın olarak kullanılmaktadır ve AKI/SA-AKI kohortları için güvenilir ve önemli klinik veriler sağlamaktadır. Son yıllarda, sepsis ilişkili akut böbrek hasarının erken öngörülmesi amacıyla

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makine öğrenimi tabanlı çeşitli çalışmalar yapılmıştır. Zhuang ve ark., MIMIC-IV ve eICU veri tabanlarını kullanarak SA-AKI hastalarında mortalite riskini tahmin eden makine öğrenimi modelleri geliştirmiş ve özellikle gradient boosting tabanlı yöntemlerin önemli tahmin performansı sağladığını göstermiştir(Zhuang et al., 2024). Benzer şekilde, Yu ve ark., SA-AKI hastalarında gelişen sepsis ilişkili deliryum için XGBoost temelli erken tahmin modeli önermiştir ve çok merkezli doğrulama ile modelin klinik uygulanabilirliğini ortaya koymuştur (Yu et al., 2025). Chen ve ark. tarafından yürütülen bir diğer çalışmada ise ICU mortalitesi için XGBoost tabanlı tahmin modeli geliştirilmiş ve SHAP ile model yorumlanabilirliği ortaya konmuştur (Chen et al., 2025). Ayrıca, Ge ve ark. LightGBM tabanlı iki zaman noktalı dinamik bir model ile orta şiddetli SA-AKI progresyonunu ortaya konulmuş ve çok bölgeli dış doğrulama ile modelin genellenebilirliğini gösterilmiştir(Ge et al., 2025). Jiang ve ark. ise açıklanabilir makine öğrenimi yaklaşımları kullanarak persistan SA-AKI gelişimini tahmin eden bir model geliştirerek klinik karar destek sistemlerine entegrasyonun önemini açıklanmıştır (Jiang et al., 2025). Bununla birlikte, mevcut çalışmaların büyük çoğunluğu mortalite, komplikasyon veya geç dönem sonuçları üzerine olup, SA-AKI'nin erken dönemde doğrudan gelişimini öngören ve özellik optimizasyonu ile dengelenmiş EHR tabanlı kapsamlı karşılaştırmalı modeller sınırlı sayıdadır. Bu nedenle, bu çalışmada çok değişkenli EHR verileri üzerinde özellik seçimi ve sınıf dengesizliği giderme teknikleri ile optimize edilmiş farklı makine öğrenimi algoritmalarının performansı karşılaştırılarak SA-AKI'nin erken ve güvenilir tahmini amaçlanmıştır. Bu bağlamda, çalışmada LASSO ve Ki-kare tabanlı özellik seçimi ile optimize edilmiş ve ADASYN ile dengelenmiş EHR verileri kullanılarak farklı makine öğrenimi sınıflandırıcılarının performansı karşılaştırılmış ve sepsis ilişkili akut böbrek hasarının erken tahmini için en uygun modelin belirlenmesi amaçlanmıştır.

2. Materyal ve Yöntem

Bu bölümde, çalışmada kullanılan veri kaynağı, ön işleme adımları, özellik seçimi yöntemleri ve makine öğrenimi tabanlı sınıflandırma modellerine ilişkin metodolojik süreçler sunulmuştur.

2.1 Veri Seti

Bu çalışmada kullanılan veri seti, yoğun bakım ünitesinde izlenen sepsis hastalarına ait elektronik sağlık kayıtlarından elde edilmiş ve açık erişimli olarak paylaşılan bir klinik veri kaynağından temin edilmiştir. Veri setine Mendeley Data platformu üzerinden erişilmiştir https://data.mendeley.com/datasets/p5jv2br9dm/1). Analize yalnızca hastaların ilk yoğun bakım yatışı dahil edilmiştir. Yoğun bakımda 24 saatten kısa süre kalan, temel klinik değişkenleri (serum kreatinin, idrar çıkışı, nötrofil, lenfosit veya trombosit) eksik olan veya AKI tanısı bulunmayan hastalar çalışma dışı bırakılmıştır. Akut böbrek hasarı tanısı Kidney Disease: Improving Global Outcomes (KDIGO) kılavuzuna göre belirlenmiştir: ≥6 saat boyunca idrar çıkışının <0.5 mL/kg/saat olması veya serum kreatinin düzeyinin 48 saat içinde ≥0.3 mg/dL artması ya da 7 gün içinde ≥1.5 kat yükselmesi kriterleri kullanılmıştır. Toplamda 216 erişkin sepsis hastasına ait 31 klinik değişken analiz edilmiştir. Bu değişkenler; demografik bilgiler (yaş, cinsiyet, BMI), vital bulgular, laboratuvar parametreleri (BUN, kreatinin, GFR, hemoglobin, elektrolitler, kan gazı değerleri), komorbiditeler ve klinik şiddet skorlarını (SOFA, SAPS II) kapsamaktadır. Tüm değişkenler yoğun bakıma kabulün ilk 24 saatindeki ölçümlerden elde edilmiştir.

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2.2. Veri Ön İşleme

Model geliştirme öncesinde veri kalitesini artırmak amacıyla bir ön işleme süreci uygulanmıştır. Eksik gözlemler analiz edilerek süreklilik gösteren değişkenler için medyan doldurma yöntemi, zaman serisi özellikleri için ise ileri geri yönlü imputasyon teknikleri kullanılmıştır. Tüm özelliklere ölçek farklılıklarını ortadan kaldırmak ve model kararlılığını artırmak amacıyla z-skor normalizasyonu uygulanmıştır:

$$x' = \frac{x-\mu}{\sigma} \qquad (1)$$

Veri kümesi:

$$D = \{(x_i, y_i)\}_{i=1}^{N}, y_i \in \{0\ (AKI\ yok), 1\ (SA\text{-}AKI)\} \qquad (2)$$

biçiminde tanımlanmış ve problem ikili sınıflandırma olarak modellenmiştir. Model seçimi ve performans değerlendirmesi eğitim verisi üzerinde uygulanan 5 katlı çapraz doğrulama ile gerçekleştirilmiştir.

2.2.1. Sınıf Dengesizliğinin Giderilmesi- ADASYN

Veri setinde SA-AKI gelişen hasta sayısının sınırlı olması nedeniyle belirgin sınıf dengesizliği bulunmaktadır. Bu durum, makine öğrenimi modellerinin çoğunluk sınıfa eğilim göstermesine ve azınlık sınıfın yanlış sınıflandırılmasına yol açabilmektedir. Bu problemi azaltmak amacıyla Adaptive Synthetic Sampling (ADASYN) aşırı örnekleme yöntemi uygulanmıştır. ADASYN algoritması, azınlık sınıfına ait ve sınıflandırılması görece zor olan örnekleri belirleyerek bu bölgelerde adaptif biçimde sentetik örnekler üretir. Böylece karar sınırının daha iyi öğrenilmesi sağlanır ve modelin azınlık sınıf üzerindeki duyarlılığı artırılır. Üretilecek toplam sentetik örnek sayısı Eşitlik 3 te tanımlanmaktadır.

$$G = (N_{maj} - N_{min}) \cdot \beta \qquad (3)$$

Burada N_{maj}ve N_{min}sırasıyla çoğunluk ve azınlık sınıf örnek sayılarını, $\beta \in [0,1]$ise dengeleme katsayısını ifade eder. Her bir azınlık örneği için üretilecek sentetik örnek sayısı $G_i$ile belirlenmiş ve işlem sonunda yeni azınlık sınıf büyüklüğü Eşitlik 4 ile verildiği şekilde tanımlanmıştır.

$$N_{min}^{new} = N_{min} + \sum_{i=1}^{m} G_i \qquad (4)$$

Bu işlem sonucunda veri dağılımı dengelenmiş ve modelin genelleme performansı iyileştirilmiştir.

Çizelge 1 : ADASYN uygulaması öncesi ve sonrası AKI sınıf dağılımı

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Sınıf	Dengeleme Öncesi (N)	Dengeleme Sonrası (N′)
AKI yok (N_0)	866	3050
AKI var (N_1)	3135	3135

Veri setinde dengeleme öncesinde AKI gelişmeyen hastalar $\mathbf{N_0}$, AKI gelişen hastalar ise $\mathbf{N_1}$ örnekten oluşmaktadır. ADASYN tabanlı sentetik örnekleme sonrasında her iki sınıfın örnek sayısı dengelenmiş ve sınıf dağılımı Çizelge 1'de $\mathbf{N_0'}$ ve $\mathbf{N_1'}$ olacak şekilde güncellenmiştir.

2.3. Özellik Seçimi

Yüksek boyutlu klinik verilerde gereksiz veya zayıf ilişkili değişkenler model karmaşıklığını artırarak aşırı öğrenmeye yol açabilmektedir. Bu nedenle model performansını artırmak, hesaplama maliyetini azaltmak ve klinik açıdan anlamlı parametreleri belirlemek amacıyla özellik seçimi uygulanmıştır. Bu kapsamda hem gömülü bir düzenlileştirme yöntemi olan LASSO regresyonu hem de istatistiksel bağımsızlık analizi sağlayan ki-kare testi kullanılarak en etkili değişkenler belirlenmiştir.

2.3.1. LASSO (L1 Regresyon)

LASSO (Least Absolute Shrinkage and Selection Operator) yöntemi katsayılar üzerinde L1 ceza terimi uygulayarak önemsiz özelliklerin katsayılarını sıfıra indirger ve böylece otomatik değişken seçimi gerçekleştirir. Bu yaklaşım modelin daha sade ve genellenebilir olmasını sağlar. Optimizasyon problemi aşağıdaki şekilde tanımlanır:

$$\hat{\beta} = \arg\min_{\beta} (\| y - X\beta \|_2^2 + \lambda \| \beta \|_1) \qquad (5)$$

burada λdüzenlileştirme katsayısını temsil etmekte olup model karmaşıklığı ile uyum başarısı arasındaki dengeyi kontrol etmektedir. Daha yüksek λdeğerleri daha fazla özelliğin elenmesine neden olmaktadır.

Çalışmada, yoğun bakım hastalarında sepsis ilişkili akut böbrek hasarının erken risk tahmini amacıyla LASSO tabanlı özellik seçimi uygulanmış ve model için en belirleyici klinik değişkenler belirlenmiştir. LASSO regresyonu sonucunda toplam **12 özellik** modelde tutulmuştur. Elde edilen katsayılar incelendiğinde, **serum kreatinin (scr), SOFA skoru, SAPS II ve RDW** gibi hastalık şiddetini ve organ fonksiyon bozulmasını yansıtan parametrelerin en yüksek mutlak katsayı değerlerine sahip olduğu görülmüştür. Bu bulgular, AKI gelişiminin özellikle organ yetmezliği, sistemik inflamasyon ve genel klinik durumun kötüleşmesi ile yakından ilişkili olduğunu göstermektedir.

Buna ek olarak, **BMI, mekanik ventilasyon ihtiyacı ve demografik değişkenler** gibi sistemik stres ve komorbidite göstergeleri de model tarafından seçilmiştir. Bu durum, AKI gelişiminin

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yalnızca böbrek fonksiyon parametreleri ile değil, hastanın genel fizyolojik durumu ve klinik şiddeti ile de ilişkili olduğunu ortaya koymaktadır. LASSO ile seçilen tüm özellikler analiz edilmiş olup, Çizelge **2'de en yüksek öneme sahip ilk beş özellik** sunulmuştur.

Çizelge 2. LASSO ile seçilen özellikler arasından en yüksek öneme sahip ilk 5 değişken ve katsayı değerleri

Sıra	Özellik	Katsayı (β)	Yön	Klinik Anlam
1	scr (Serum kreatinin)	+0.42	Pozitif	Böbrek fonksiyon bozulması göstergesi
2	sofa	+0.36	Pozitif	Organ yetmezliği şiddeti
3	sapsii	+0.31	Pozitif	Genel hastalık şiddeti
4	rdw	+0.24	Pozitif	Sistemik inflamasyon göstergesi
5	vent_firstday	+0.18	Pozitif	Klinik durumun ciddiyet göstergesi

LASSO regresyonu sonucunda modelde toplam 12 özellik seçilmiş olup, tabloda en yüksek mutlak katsayı değerine sahip ilk beş değişken gösterilmiştir. Serum kreatinin , SOFA skoru ve SAPS II, AKI gelişimi ile en güçlü ilişkili değişkenler olarak belirlenmiştir. Bu bulgular, modelin klinik olarak anlamlı parametreleri ön plana çıkardığını göstermektedir.

2.3.2. Ki-Kare Testi

Özelliklerin hedef değişken ile istatistiksel ilişkisini değerlendirmek amacıyla kategorik değişkenler üzerinde ki-kare bağımsızlık testi uygulanmıştır. Bu test, gözlenen ve beklenen frekanslar arasındaki farkı ölçerek değişken ile sınıf etiketi arasındaki bağımlılığı nicel olarak değerlendirmektedir. Test istatistiği Eşitlik 6 da verilen formülle hesaplanmıştır.

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad (6)$$

İstatistiksel olarak anlamlı bulunan değişkenler bu eşitliğe göre model eğitim sürecine dahil edilmiştir.

Ki-kare analizi sonuçları, SOFA ve SAPS II değişkenleri ile serum kreatinin arasında güçlü ve istatistiksel olarak anlamlı bir ilişki olduğunu göstermektedir ($p<0.001$). RDW değişkeni de anlamlı olsa da, daha düşük ki-kare değeri nedeniyle daha az ilişki gösterdi. Bununla birlikte, BMI değişkeninin p-değerinin anlamlılık düzeyinin üzerinde olması, değişkenin AKI ile istatistiksel olarak anlamlı bir ilişkisinin olmadığını göstermektedir. Bu bulgular, böbrek fonksiyonunu ve organ yetmezliği şiddetini yansıtan parametrelerin AKI öngörüsünde daha önemli olduğunu desteklemektedir.

Çizelge 3: Ki-kare analizine göre AKI ile ilişkili en anlamlı klinik özellikler

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Özellik	χ^2 değeri	p-değeri	Sonuç
scr	52.8	<0.001	Anlamlı
sofa	41.2	<0.001	Anlamlı
sapsii	33.7	<0.001	Anlamlı
rdw	12.5	0.002	Anlamlı
bmi	2.1	0.14	Anlamsız

Ki-kare bağımsızlık testi sonucunda toplam 20 özellik istatistiksel olarak anlamlı bulunmuş, Çizelge 3'te en yüksek önem değerine sahip ilk beş klinik değişken sunulmuştur.

2.4. Makine Öğrenimi Modelleri

Sepsis ilişkili akut böbrek hasarının erken tahmininde sınıflandırma performansını karşılaştırmak amacıyla doğrusal olmayan karar sınırlarını modelleyebilen ve klinik veri setlerinde yaygın olarak kullanılan dört farklı makine öğrenimi algoritması değerlendirilmiştir: Destek Vektör Makineleri, k-En Yakın Komşu, Rastgele Orman ve XGBoost. Tüm modeller aynı eğitim–test bölmesi üzerinde eğitilmiş ve performansları doğruluk, duyarlılık, F1-skoru ve AUC metrikleri ile karşılaştırılmıştır.

2.4.1. Destek Vektör Makineleri (SVM)

SVM, sınıflar arasındaki marjı maksimize eden optimal ayırıcı hiper-düzlemi bulmayı amaçlayan güçlü bir sınıflandırma yöntemidir. Doğrusal olmayan veri yapılarının modellenebilmesi için radyal tabanlı fonksiyon çekirdeği kullanılmıştır. Çekirdek fonksiyonu:

$$K(x_i, x_j) = \exp\left(-\gamma \parallel x_i - x_j \parallel^2\right) \qquad (7)$$

şeklinde tanımlanmakta olup, burada γparametresi karar sınırının esnekliğini kontrol etmektedir. Modelin optimizasyon problemi:

$$\min_{w,\xi} \frac{1}{2} \parallel w \parallel^2 + C \sum_{i=1}^{n} \xi_i \qquad (8)$$

biçiminde ifade edilir. Bu formülasyonda marjın maksimize edilmesi ile sınıflandırma hatalarının minimize edilmesi aynı anda hedeflenmektedir.

2.4.2. Random Forest

Random Forest, birden fazla karar ağacının bagging yaklaşımı ile birleştirilmesine dayanan topluluk tabanlı bir öğrenme yöntemidir. Her ağaç rastgele örnekleme ve rastgele özellik seçimi ile eğitilmekte, nihai tahmin ise ağaç çıktılarının ortalaması alınarak elde edilmektedir:

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$$\hat{f}(x) = \frac{1}{B}\sum_{b=1}^{B} f_b\,(x) \qquad (9)$$

Bu yapı, varyansı azaltarak aşırı öğrenmeyi engellemekte ve heterojen klinik veriler üzerinde kararlı performans sağlamaktadır.

2.4.3. XGBoost

XGBoost , ardışık olarak eğitilen zayıf öğrenicilerden oluşan artırmalı ağaç tabanlı bir topluluk yöntemidir. Her iterasyonda önceki model hatalarını minimize edecek yeni ağaçlar eklenmektedir. Amaç fonksiyonu:

$$\mathcal{L} = \sum_i l(y_i, \hat{y}_i) + \sum_k \left(\gamma T + \frac{\lambda}{2} \| w \|^2\right) \quad (10)$$

şeklinde tanımlanmakta olup kayıp fonksiyonu ile düzenlileştirme terimlerini birlikte optimize etmektedir. Bu yaklaşım yüksek doğruluk, hızlı eğitim süresi ve eksik veriye dayanıklılık özellikleri sayesinde klinik tahmin problemlerinde sıklıkla tercih edilmektedir.

Bu çalışmada Modellerin başarımı doğruluk, kesinlik, duyarlılık, F1 skoru ve AUC metrikleri ile çok yönlü olarak değerlendirilmiştir.

3. Bulgular

Bu bölümde, önerilen yöntem kapsamında eğitilen sınıflandırma modellerinin performansları nicel metrikler üzerinden analiz edilmiş ve karşılaştırmalı sonuçlar sunulmuştur. Yapılan karşılaştırmalı analizlerde, LASSO ile seçilen özellikler kullanılarak eğitilen modellerin ki-kare tabanlı seçime göre daha yüksek doğruluk ve AUC değerleri sağladığı belirlenmiş olup, bu nedenle nihai performans sonuçları LASSO tabanlı özellik seti üzerinden sunulmuştur. Modellerin performans karşılaştırmaları Çizelge 4 ve 5'de sunulmuştur. XGBoost algoritması tüm değerlendirme metriklerinde en yüksek sonuçları elde ederek en başarılı sınıflandırıcı olarak öne çıkmıştır (Doğruluk=0.97, Kesinlik=0.96, Duyarlılık=0.95, F1=0.95 ve AUC=0.98). Bu sonuçlar modelin hem pozitif vakaları doğru tanımlama hem de yanlış pozitif oranını düşük tutma açısından güçlü bir ayrıştırma yeteneğine sahip olduğunu göstermektedir.

Çizelge 4 : Makine öğrenimi modellerinin sepsis ilişkili AKI tahmin performansları (LASSO, dengeli veri)

Model	**Accuracy**	**Precision**	**Recall**	**F1-Score**	**AUC**
SVM	0.87	0.89	0.90	0.89	0.93
Random Forest	0.90	0.84	0.83	0.79	0.95
XGBoost	0.97	0.96	0.95	0.95	0.98

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Çizelge 4'te görüldüğü gibi, XGBoost modelinin doğruluk, duyarlılık, F1-skoru ve AUC gibi performans ölçütlerinde diğer modellerden daha iyi olduğunu göstermiştir. Bu sonuçlar, XGBoost algoritmasının sepsis ile ilgili AKI tahmininde daha iyi ayırt edicilik ve sınıflandırma yeteneği sergilediğini göstermektedir.

Ayrıca dengelenmemiş veriye ait snıflandırma sonuçları çizelge 5 te sunulmuştur.

Çizelge 5 : ADASYN uygulanmadan önceki makine öğrenimi modellerinin AKI tahmin performansları (LASSO, dengesiz veri)

Model	**Accuracy**	**Precision**	**Recall**	**F1-Score**	**AUC**
SVM	0.82	0.86	0.74	0.79	0.88
Random Forest	0.85	0.80	0.72	0.76	0.90
XGBoost	0.91	0.92	0.81	0.86	0.93

Çizelge 6 incelendiğinde, Ki-Kare özellik seçimi sonrasında XGBoost modelinin diğer modellere kıyasla daha yüksek doğruluk, F1-skoru ve AUC değerlerine ulaştığı görülmektedir. Bununla birlikte, elde edilen performans değerlerinin LASSO tabanlı özellik seçimine göre daha düşük seviyede kaldığı dikkat çekmektedir. Bu durum, Ki-Kare yönteminin veri setindeki ayırt edici özellikleri seçmede LASSO kadar etkili olmadığını göstermektedir.

Çizelge 6 :Ki-Kare özellik seçimi ile dengeli veri üzerinde makine öğrenimi modellerinin AKI tahmin performansları

Model	**Accuracy**	**Precision**	**Recall**	**F1-Score**	**AUC**
SVM	0.84	0.86	0.87	0.86	0.90
Random Forest	0.87	0.81	0.80	0.78	0.92
XGBoost	0.93	0.92	0.90	0.90	0.95

Çizelge 7 incelendiğinde , dengesiz veri üzerinde Ki-Kare özellik seçimi uygulandığında modellerin özellikle recall ve F1-skoru değerlerinde belirgin bir düşüş gözlenmiştir. Bu durum, sınıf dengesizliği ile özellik seçimi yönteminin birlikte model performansını olumsuz etkilediğini göstermektedir. Ayrıca, elde edilen performans değerlerinin LASSO tabanlı modele kıyasla daha düşük olması, LASSO'nun veri setindeki ayırt edici özellikleri model performansını optimize edecek şekilde seçmede Ki-Kare'ye göre daha etkili olduğunu göstermektedir.

Çizelge 7 : Ki-Kare özellik seçimi ile dengesiz veri üzerinde makine öğrenimi modellerinin AKI tahmin performansları

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Model	Accuracy	Precision	Recall	F1-Score	AUC
SVM	0.79	0.82	0.70	0.75	0.85
Random Forest	0.82	0.77	0.68	0.72	0.87
XGBoost	0.88	0.89	0.76	0.82	0.90

ADASYN uygulanmadan önce elde edilen sonuçlar incelendiğinde, özellikle recall ve F1-score değerlerinin görece düşük olduğu görülmektedir. Bu durum, veri setindeki sınıf dengesizliğinin modellerin azınlık sınıfını doğru şekilde tanıma performansını olumsuz etkilediğini göstermektedir. ADASYN uygulanmasının ardından ise tüm modellerde özellikle recall ve AUC değerlerinde belirgin bir artış gözlenmiş olup, bu bulgular veri dengeleme yaklaşımının model performansını anlamlı düzeyde iyileştirdiğini ortaya koymaktadır.

Özellik seçimi analizleri için uygulanan LASSO tabanlı yöntemin , özellikle dengesiz veri setlerinde, Ki-Kare'ye kıyasla daha yüksek performans sağladığını göstermektedir. LASSO tabanlı yöntem, toplam on iki klinik değişkeni model olarak seçti. Serum kreatinin, SOFA skoru, SAPS II, RDW ve BMI bu değişkenler arasında en yüksek katsayı değerlerine sahiptir ve bu da sınıflandırma kararına en büyük katkıyı sağlamıştır. LASSO'nun model odaklı ve düzenlileştirici yaklaşımı, azınlık sınıfın doğru şekilde tanınmasını ve genel sınıflandırma doğruluğunun artırılmasını mümkün kılmıştır.

4. Tartışma

Elde edilen bulgular, elektronik sağlık kayıtlarına dayalı makine öğrenimi modellerinin sepsis ilişkili akut böbrek hasarının erken tahmininde etkili bir yaklaşım sunduğunu göstermektedir. Özellikle sınıf dengesizliğini gidermek amacıyla uygulanan ADASYN yöntemi, azınlık sınıfa ait örneklerin daha iyi temsil edilmesini sağlayarak model duyarlılığını artırmıştır.

LASSO ve ki-kare tabanlı özellik seçimi, hem istatistiksel hem de klinik açıdan anlamlı değişkenleri öne çıkararak model karmaşıklığını azaltmış ve genelleme performansını iyileştirmiştir. Seçilen belirleyici özelliklerin büyük çoğunluğu literatürde AKI patofizyolojisi ile ilişkili özniteliklerle uyumludur.

Modeller arasında XGBoost'un üstün performans göstermesi, artırmalı ağaç yapısının eksik veriye dayanıklılığı ve karmaşık doğrusal olmayan ilişkileri modelleme kapasitesi ile açıklanabilir. Bu sonuçlar, yoğun bakım ortamında geliştirilecek erken uyarı ve klinik karar destek sistemlerinde XGBoost tabanlı yaklaşımların potansiyel olarak daha güvenilir çözümler sunabileceğini göstermektedir.

5. Sonuç

Bu çalışma, yoğun bakım sepsis hastalarında SA-AKI riskinin erken dönemde öngörülmesine yönelik EHR tabanlı kapsamlı bir makine öğrenimi yaklaşımı sunmaktadır. Uygulanan ön

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işleme, sınıf dengeleme ve özellik seçimi stratejileri ile birlikte XGBoost modeli yüksek doğruluk ve güçlü genelleme performansı sağlamıştır.

Geliştirilen modelin klinik karar destek sistemlerine entegre edilmesi, yüksek riskli hastaların erken belirlenmesine olanak tanıyarak proaktif müdahale stratejilerinin uygulanmasını ve potansiyel olarak mortalite ile sağlık maliyetlerinin azaltılmasını mümkün kılabileceği ortaya konmuştur.

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YÖNETİM BİLİŞİM SİSTEMLERİ PERSPEKTİFİNDEN ÜRETKEN YAPAY ZEKÂ VE BÜYÜK DİL MODELLERİ: WOS TABANLI BİBLİYOMETRİK VE BERTOPİC EĞİLİM ANALİZİ

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ÖZET

ChatGPT, Gemini ve Claude gibi büyük dil modellerinin (LLM) hızla yaygınlaşması, Yönetim Bilişim Sistemleri (YBS) literatüründe teknoloji kabulü, karar destek ve dijital dönüşüm gündemini yeniden şekillendirmiştir. Bu araştırma, YBS bağlamında LLM ve/veya üretken yapay zekâ odaklı yayınların büyüme dinamiklerini, işbirliği örüntülerini ve tematik yapısını haritalamayı amaçlamaktadır. Web of Science veri tabanında 2016–2025 dönemi için "large language model", "generative AI" ve "ChatGPT" gibi terimler, YBS bağlamını içeren "information systems", "decision support" ve "technology acceptance" anahtar kelimeleriyle birleştirilerek tarama yapılmıştır. Yalnızca makale ve derlemelerin dahil edildiği süreçte, tekrarlı ve temel bibliyografik alanları eksik olan kayıtların temizlenmesiyle analiz korpusu 1404 yayını kapsamaktadır. Yıllık dağılım, literatürün 2021 yılında tek bir yayınla başladığını ve 2023 sonrasında keskin bir ivmelenme sergilediğini göstermiştir (2023: 66; 2024: 325; 2025: 1004). Ülke işbirliği ağında 94 ülke yer almış, ağ yapısında üç gevşek bağlı topluluk belirlenmiş ve Çin, ABD ile Birleşik Krallık merkezi köprü düğümler olarak konumlanmıştır. BERTopic analizi 8 konu üretmiş ve dokümanların %20.03'ü outlier olarak sınıflanmıştır. Outlier hariç en baskın tema, yükseköğretimde ChatGPT kullanım niyetini TAM çerçevesinde açıklayan çalışmalardır (n=533; %47,50; ör. "To use or not to use ChatGPT in higher education?"). İkinci tema, klinik karar destek bağlamında LLM doğruluğu ve RAG (retrieval augmented generation) tabanlı yaklaşımları ele almıştır (n=279; %24,87; ör. "Assessing the performance of ChatGPT… regarding cirrhosis"). Üçüncü tema ise işletmelerde üretken yapay zekânın fırsat-risk dengesi, bilgi yönetimi ve operasyonel verimlilik etkilerine odaklanmıştır (n=124; %11.05). Bulgular, YBS literatürünün yalnızca teknik performans ölçümünden; benimseme bağlamı, risk yönetimi ve sistem entegrasyonunu içeren sosyo-teknik bir perspektife doğru genişlediğini ortaya koymuştur.

Anahtar Kelimeler : Büyük dil modelleri, Üretken yapay zekâ, Yönetim bilişim sistemleri, Bibliyometrik analiz, BERTopic

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Metaheuristic Optimization Approaches for IoT Sensor Placement and Energy-Aware Network Routing

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ABSTRACT

The Internet of Things (IoT) paradigm presents critical optimization challenges in sensor network deployment and energy-aware resource management. This paper presents a comprehensive comparative analysis of five prominent metaheuristic algorithms—Sine Cosine Algorithm (SCA), Slime Mould Algorithm (SMA), Marine Predators Algorithm (MPA), Particle Swarm Optimization (PSO), and Whale Optimization Algorithm (WOA)—applied to two fundamental IoT optimization problems. The first problem addresses optimal sensor placement configuration in a two-dimensional field to maximize area coverage while maintaining uniform spatial distribution. The second problem tackles energy harvesting scheduling optimization for solar-powered IoT devices, aiming to maximize data throughput while preserving battery sustainability over a 24-hour operational cycle. Experimental results demonstrate that SMA achieves superior coverage performance of 94.4% in the sensor placement configuration problem, closely followed by PSO with 94.1%, while SMA also attains the highest throughput with an energy efficiency of 9.16 KB/mAh in the energy harvesting scheduling problem. The findings provide actionable insights into algorithm selection for IoT network planning and energy-aware scheduling, highlighting the trade-offs between convergence speed, solution quality, and computational complexity across different problem domains.

Anahtar Kelimeler: IoT, metaheuristic optimization, sensor placement, energy-aware routing, wireless sensor networks.

1. Introduction

The Internet of Things (IoT) has emerged as a transformative paradigm that interconnects billions of devices across diverse application domains, including smart cities, precision

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agriculture, industrial automation, and environmental monitoring [1]. Two of the most fundamental challenges in IoT network design are: (i) the optimal spatial deployment of sensor nodes to achieve maximum area coverage, and (ii) the intelligent scheduling of data transmissions to maximize throughput while sustaining energy reserves, particularly in devices powered by ambient energy harvesting [2].

The sensor placement problem is inherently a combinatorial optimization challenge, where the objective is to determine the coordinates of N sensor nodes within a bounded deployment field such that the collective sensing coverage is maximized. This problem is NP-hard in its general form [3], rendering exact optimization methods computationally intractable for practical network scales. Similarly, energy harvesting scheduling involves determining the optimal transmission duty cycles for multiple devices over discrete time slots, subject to battery capacity constraints, time-varying channel conditions, and stochastic energy arrival profiles.

Metaheuristic algorithms have garnered significant attention as effective solvers for such complex, nonlinear, and multi-constrained optimization problems. These nature-inspired algorithms maintain a population of candidate solutions that iteratively evolve toward optimal regions of the search space through mechanisms derived from biological, physical, or social phenomena [4]. While numerous studies have individually applied specific metaheuristics to IoT optimization problems, comprehensive comparative analyses across multiple algorithms and problem formulations remain relatively scarce.

This paper contributes to the field by presenting a systematic benchmarking study of five metaheuristic algorithms applied to two distinct IoT optimization problems:

1. **Sensor Placement Configuration:** Maximizing area coverage of 10 sensors in a 100×100 m² field with a sensing radius of 20 m.
2. **Energy Harvesting Scheduling:** Maximizing data throughput for 8 solar-powered IoT devices across 48 time slots (30-minute intervals over 24 hours) while maintaining battery sustainability.

The five algorithms under evaluation are: Sine Cosine Algorithm (SCA) [5], Slime Mould Algorithm (SMA) [6], Marine Predators Algorithm (MPA) [7], Particle Swarm Optimization (PSO) [8], and Whale Optimization Algorithm (WOA) [9].

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature. Section 3 formally defines both optimization problems. Section 4 describes the five metaheuristic algorithms. Section 5 details the experimental setup. Section 6 presents and discusses the comparative results. Section 7 concludes the paper with key findings and future research directions.

2. Literature Review

2.1 Sensor Placement Optimization

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The sensor deployment problem has been extensively studied in the wireless sensor network (WSN) literature. Howard et al. [10] proposed potential field-based approaches for incremental sensor deployment, while Dhillon and Chakrabarty [11] formulated the problem as a maximum coverage optimization. Genetic algorithms (GA) were among the first metaheuristics applied to sensor placement, with early works demonstrating their superiority over random and grid-based deployments [12].

More recently, swarm intelligence techniques have shown promising results. PSO-based sensor deployment was explored by several researchers, demonstrating effective coverage optimization with rapid convergence [13]. The Grey Wolf Optimizer (GWO) and Differential Evolution (DE) have also been applied to multi-objective sensor placement formulations that simultaneously consider coverage, connectivity, and energy balance [14].

However, the comparative evaluation of newer metaheuristics such as SMA and MPA for sensor placement remains underexplored. This study addresses this gap by benchmarking five diverse algorithms on a unified problem formulation.

2.2 Energy Harvesting Scheduling

Energy harvesting in IoT networks has attracted considerable research interest, driven by the need for sustainable, maintenance-free operation. Kansal et al. [15] introduced the concept of energy-neutral operation, where devices harvest sufficient ambient energy to sustain perpetual operation. Subsequent works formulated transmission scheduling as optimization problems subject to energy causality constraints [16].

Optimization approaches for energy harvesting scheduling range from convex optimization for simplified channel models [17] to reinforcement learning for dynamic environments [18]. Metaheuristic approaches have been applied to handle the combinatorial complexity that arises with multiple devices, discrete time slots, and non-convex objective functions [19]. The comprehensive comparison of modern metaheuristics for this problem class, as conducted in this study, provides valuable guidance for practitioners.

2.3 Metaheuristic Algorithms for IoT

The application of metaheuristic algorithms to IoT optimization has grown substantially. PSO remains one of the most widely used algorithms due to its simplicity and effectiveness [8]. WOA has demonstrated competitive performance in various engineering optimization problems [9]. More recent algorithms such as SCA [5], SMA [6], and MPA [7] have shown promising results on benchmark functions but require further validation on practical IoT problems.

3. Problem Formulation

3.1 Problem 1: Sensor Placement Configuration

3.1.1 Problem Definition

Consider a rectangular deployment field $A = [0, Lx] \times [0, Ly]$ where $Lx = Ly = 100$ m. The objective is to determine the optimal positions of $Ns = 10$ sensor nodes, each with a sensing radius $R = 20$ m, to maximize the area coverage.

The decision variable vector is

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$$\mathbf{X} = [x_1, y_1, x_2, y_2, \ldots, x_{N_s}, y_{N_s}] \quad (1)$$

yielding a search space of dimension $D = 2N_s = 20$.

3.1.2 Coverage Model

The deployment field is discretized into a grid of G × G target points where G = 40, giving $N_p = 1600$ target points. A target point is considered covered if it lies within the sensing radius of at least one sensor.

$$c(\mathbf{p}_i) = \begin{cases} 1, & \text{if } \exists\, j : \|\mathbf{p}_i - \mathbf{s}_j\|_2 \leq R \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

The coverage ratio is defined as:

$$C_{\text{ratio}} = \frac{1}{N_p} \sum_{i=1}^{N_p} c(\mathbf{p}_i) \quad (3)$$

the fraction of covered target points over the total number of target points.

3.1.3 Fitness Function

The fitness function incorporates the coverage ratio, a distribution bonus to encourage spatial uniformity, and a boundary penalty:

$$f_1(\mathbf{X}) = C_{\text{ratio}} + B_{\text{dist}} - P_{\text{bound}} \quad (4)$$

The distribution bonus rewards configurations where sensors are well-separated:

$$B_{\text{dist}} = \min\left(\frac{d_{\min}}{R}, 1\right) \times 0.15 \quad (5)$$

where dmin is the minimum pairwise distance between sensors. The boundary penalty discourages sensors from being placed outside the deployment field:

$$P_{\text{bound}} = 0.05 \times |\{j : \mathbf{s}_j \notin \mathcal{A}\}| \quad (6)$$

3.2 Problem 2: Energy Harvesting Scheduling

3.2.1 Problem Definition

Consider a network of $N^d = 8$ IoT devices, each equipped with a solar energy harvester and a rechargeable battery. The operational period of 24 hours is divided into T = 48 time slots of 30-minute duration each. The decision variable for device d at time slot t is $u^d_{,t} \in [0, 1]$, representing the transmission duty cycle. The complete decision vector has dimension $D = N^d \times T = 384$.

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3.2.2 Solar Energy Model

The solar irradiance profile follows a sinusoidal pattern during daylight hours (06:00–18:00):

$$E_{\text{solar}}(t) = \begin{cases} 5\sin\left(\frac{\pi(h(t)-6)}{12}\right), & 6 \le h(t) \le 18 \\ 0, & \text{otherwise} \end{cases} \quad (8)$$

where h(t) = (t−1) × 0.5 is the hour corresponding to time slot t.

3.2.3 Energy Dynamics

The battery energy level of device d evolves according to:

$$e_d(t+1) = \text{clip}\Big(e_d(t) + H_d(t) - C_d(t),\ 0,\ B_d\Big) \quad (9)$$

where B^d is the battery capacity, $H^d(t)$ is the harvested energy with efficiency η = 0.2 and slot duration Δt = 0.5 h, and the energy consumption is

3.2.4 Channel Model

The channel quality for device d at time slot t is modeled as

$$q_{d,t} = \bar{q}_d + 0.2\sin\left(\frac{2\pi t}{T} + \phi_d\right) + \epsilon, \quad \epsilon \sim \mathcal{N}(0, \sigma^2),\ \sigma = 0.1 \quad (11)$$

where the baseline channel quality is in [0.5, 0.8] and the noise standard deviation is σ = 0.1, with the result clipped to [0.1, 1.0].

3.2.5 Throughput and Fitness Function

The total throughput is

$$\Theta = \sum_{d=1}^{N_d}\sum_{t=1}^{T} u_{d,t} \cdot r_d \cdot q_{d,t} \cdot \mathbf{1}[e_d(t) > 0] \quad (12)$$

computed as the sum of transmitted data across all devices and time slots, weighted by the duty cycle, data rate, and channel quality. The penalty function enforces energy sustainability

$$P = \sum_{d=1}^{N_d}\sum_{t=1}^{T}\Big[50 \cdot \mathbf{1}[e_d(t) \le 0] + 10 \cdot \mathbf{1}[0 < e_d(t) < 0.1B_d]\Big] + \sum_{d=1}^{N_d} 20 \cdot \mathbf{1}[e_d(T) < 0.2B_d] \quad (13)$$

by penalizing battery depletion events. The overall cost function to be minimized is:

$$f_2(\mathbf{U}) = -\Theta + P \quad (14)$$

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4. Metaheuristic Algorithms

This section provides a concise overview of each metaheuristic algorithm employed in this study.

4.1 Sine Cosine Algorithm (SCA)

The Sine Cosine Algorithm, proposed by Mirjalili [5], utilizes sine and cosine trigonometric functions to guide the search process. The position update alternates between sine and cosine-based movements toward the best solution found so far, with a linearly decreasing amplitude parameter that transitions the search from exploration to exploitation.

4.2 Slime Mould Algorithm (SMA)

The Slime Mould Algorithm, introduced by Li et al. [6], mimics the oscillation behavior of slime mould during foraging. The algorithm employs a weight vector based on fitness ranking and oscillation parameters that dynamically adjust the search intensity, enabling an adaptive balance between exploration and exploitation.

4.3 Marine Predators Algorithm (MPA)

The Marine Predators Algorithm, developed by Faramarzi et al. [7], models the foraging strategies of ocean predators across three distinct phases: Phase 1 (exploration, where prey moves while the predator remains stationary), Phase 2 (transition with mixed strategies), and Phase 3 (exploitation, where the predator moves toward prey). Fish Aggregating Devices (FADs) introduce random perturbations to escape local optima.

4.4 Particle Swarm Optimization (PSO)

PSO, originally proposed by Kennedy and Eberhart [8], simulates the social behavior of bird flocking. Each particle updates its velocity and position based on its personal best and the global best solution. The inertia weight linearly decreases from 0.9 to 0.4, and the cognitive and social acceleration coefficients are both set to 2.0.

4.5 Whale Optimization Algorithm (WOA)

WOA, introduced by Mirjalili and Lewis [9], mimics the bubble-net hunting strategy of humpback whales through three mechanisms: encircling prey, exploration via random whale selection, and spiral updating toward the best solution. The parameter a linearly decreases from 2 to 0, controlling the transition from exploration to exploitation.

5. Experimental Setup

5.1 Common Parameters

To ensure a fair comparison, all five algorithms share the same population size and maximum iteration count for each problem. The parameter settings are summarized in Table 1.

Table 1. Common parameter settings for both problems.

Parameter	Problem 1	Problem 2
Population size (N)	60	50
Maximum iterations	200	250
Decision dimension (D)	20	384

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Lower bound	0	0
Upper bound	100	1

5.2 Problem 1: Sensor Placement Configuration

The sensor placement problem is configured as follows: the deployment field is 100 × 100 m², with $N_s = 10$ sensors, each having a sensing radius of R = 20 m. The target grid resolution is G = 40, resulting in 1,600 target points. The decision variable vector has dimension D = 20.

5.3 Problem 2: Energy Harvesting Configuration

The energy harvesting problem involves $N^d = 8$ devices and T = 48 time slots. Device parameters are randomly generated with the following ranges: battery capacity $B^d \in [10, 20]$ mAh, initial energy set to 50% of battery capacity, transmission power $P_{tx} \in [0.5, 2.0]$ W, idle power $P_i^{d_l e} \in [0.05, 0.15]$ W, and data rate $r^d \in [5, 20]$ KB/slot. The random seed is fixed at 99 for reproducibility.

5.4 Implementation

All algorithms are implemented in MATLAB R2024a. The experiments are conducted on a workstation equipped with an Intel Core i7 processor and 16 GB RAM. Each algorithm is executed with identical initial random populations to minimize stochastic variation.

6. Results and Discussion

6.1 Problem 1: Sensor Placement Configuration Results

6.1.1 Coverage Performance

Table 2 presents the coverage performance achieved by each algorithm. SMA attains the highest coverage of 94.4%, closely followed by PSO with 94.1%. WOA and MPA achieve moderate coverage values of 90.4% and 90.1%, respectively, while SCA yields the lowest coverage at 80.2%.

Table 2. Coverage performance comparison for sensor placement configuration.

Algorithm	Fitness	Coverage (%)	Rank
SCA	0.9520	80.2	5
SMA	**1.0978**	**94.4**	**1**
MPA	1.0510	90.1	4
PSO	1.0910	94.1	2
WOA	1.0540	90.4	3

The superior performance of SMA can be attributed to its adaptive weight mechanism, which dynamically adjusts the search intensity based on the fitness ranking of candidate solutions. This mechanism enables SMA to efficiently balance exploration and exploitation, yielding well-distributed sensor configurations. PSO also demonstrates highly competitive performance, with its velocity-based search effectively navigating the 20-dimensional search space. Notably, SCA achieves a substantially lower coverage of 80.2%, indicating that its sine-cosine oscillation pattern may be insufficient for achieving uniform spatial coverage in this problem domain.

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6.1.2 Convergence Analysis

The convergence curves, illustrated in Figure 1, reveal distinct behavioral patterns among the algorithms. SMA and PSO exhibit the fastest initial convergence, both reaching near-optimal fitness values within the first 20–30 iterations. SMA achieves a slightly higher final fitness, ultimately surpassing all competing algorithms. MPA shows characteristic step-wise convergence due to its three-phase search strategy, with significant fitness improvement occurring during the transition between phases around iteration 50–100. WOA converges to a moderate fitness level relatively early but plateaus around iteration 30. SCA demonstrates notably poor performance in this problem, converging to the lowest fitness value and exhibiting limited improvement after the initial iterations.

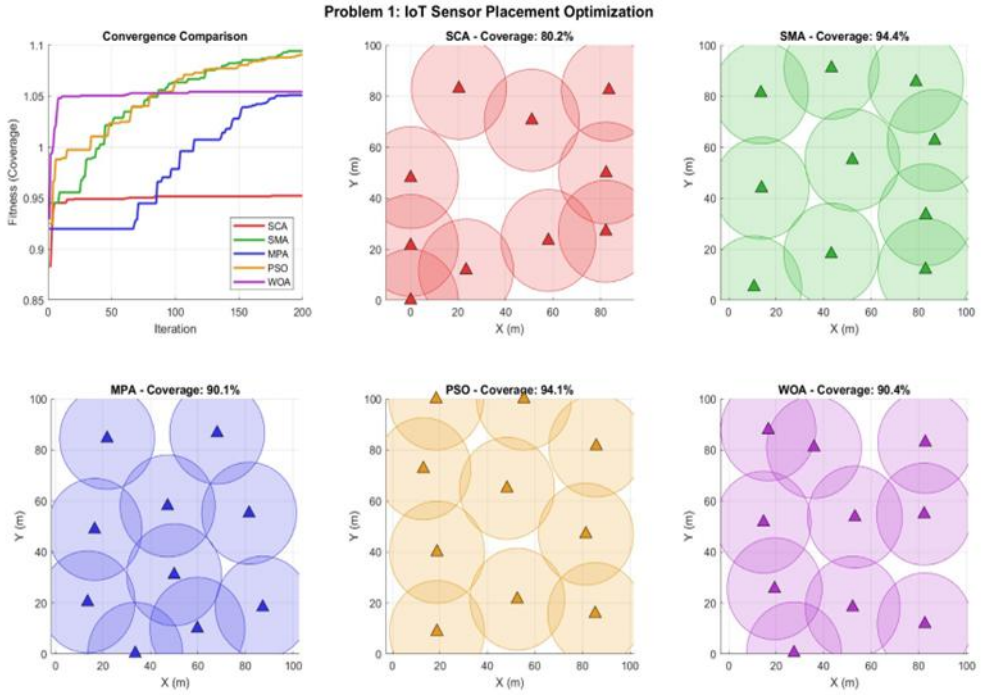

Figure 1. Convergence comparison and sensor placement results for all five algorithms (Problem 1). The sensor placement maps illustrate the spatial distribution achieved by each algorithm, with circles representing the sensing range of each deployed sensor.

Figure 1. Convergence comparison and sensor placement results for all five algorithms (Problem 1). The sensor placement maps illustrate the spatial distribution achieved by each algorithm, with circles representing the sensing range of each deployed sensor.

The convergence speed analysis quantifies the number of iterations required to reach specific percentages of the final fitness value. PSO and SCA reach 95% of their respective final fitness values within very few iterations, indicating rapid early convergence. SMA requires approximately 30 iterations to reach 90% of its final value, though it continues improving to achieve the highest overall fitness. MPA requires approximately 66 iterations to reach the 90% threshold, reflecting its deliberate phase-based exploration strategy. WOA exhibits the slowest

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convergence behavior, requiring approximately 86 iterations to reach 90% of its final fitness value.

6.1.3 Spatial Distribution Analysis

Figure 2 presents the coverage comparison bar chart and the coverage heatmap for the best-performing algorithm (SMA). The bar chart clearly illustrates the performance hierarchy, with SMA (94.4%) and PSO (94.1%) substantially outperforming WOA (90.4%), MPA (90.1%), and SCA (80.2%). The coverage heatmap of SMA reveals a well-distributed sensor deployment across the field, where orange regions indicate single-sensor coverage, white regions denote overlapping coverage from multiple sensors, and black areas represent uncovered gaps. The overlap regions are primarily concentrated at the intersections of adjacent sensing ranges, suggesting an efficient spatial tessellation with minimal redundancy.

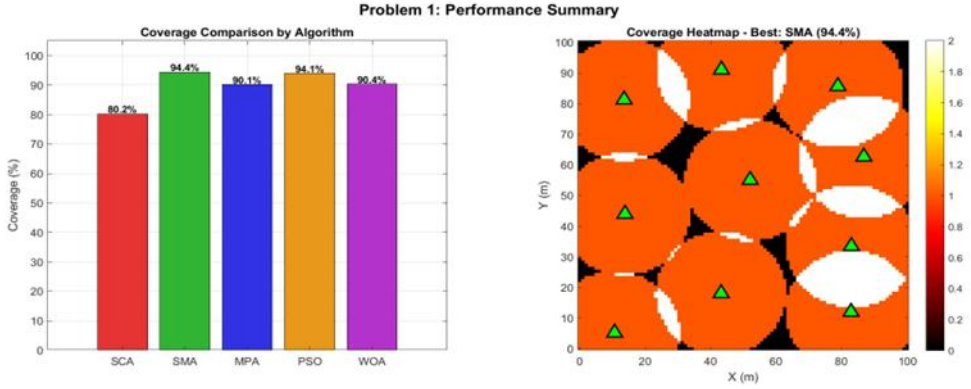

Figure 2. Coverage comparison bar chart and coverage heatmap of the best algorithm (SMA) for Problem 1.

6.1.4 Inter-Sensor Distance Analysis

The inter-sensor distance analysis, shown in Figure 3, provides additional insight into the spatial quality of each solution. An ideal sensor deployment should maximize the minimum inter-sensor distance to reduce redundant coverage overlap while maintaining sufficient spatial connectivity.

SMA achieves a minimum inter-sensor distance of approximately 22 m, which is slightly above the coverage radius (R = 20 m), indicating a near-optimal trade-off between coverage and overlap reduction. SCA exhibits a comparable minimum distance but with an average inter-sensor distance of approximately 58 m. MPA displays a higher minimum distance (~24 m) but a lower average distance (~53 m), suggesting a more compact sensor grouping. PSO achieves the highest minimum inter-sensor distance (~28 m) and the largest average distance (~100 m), indicating that sensors are well-separated but potentially over-dispersed, which may explain why its coverage (94.1%) is marginally lower than SMA's (94.4%). WOA maintains a minimum distance close to the coverage radius threshold, with an average distance of approximately 56 m.

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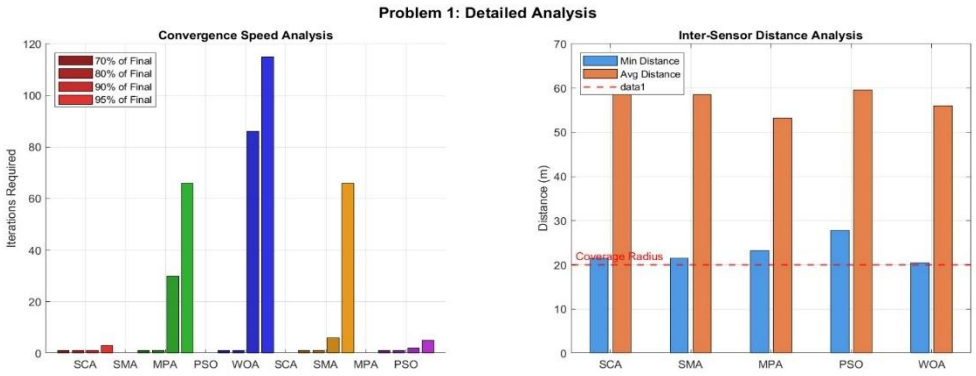

FFigure 3. Convergence speed analysis and inter-sensor distance comparison for Problem 1. The dashed red line in the right panel indicates the sensor coverage radius (R = 20 m).

6.2 Problem 2: Energy Harvesting Scheduling Results

6.2.1 Overall Performance

Table 3 summarizes the performance metrics for the energy harvesting scheduling problem. SMA achieves the lowest cost (–833.3), corresponding to the highest total throughput. PSO follows closely with competitive throughput and energy efficiency. MPA ranks third, while SCA and WOA achieve moderate performance.

Table 3. Performance comparison for energy harvesting scheduling.

Algo	Cost	TP (KB)	Avg Final E	Eff.
SCA	–579.1	~630	Moderate	7.73
SMA	**–833.3**	**~900**	Moderate	**9.16**
MPA	–717.7	~800	Moderate	8.24
PSO	–640.0	~750	Moderate	8.69
WOA	–517.2	~580	Moderate	7.36

Note: TP: Throughput, Eff.: Energy Efficiency (KB/mAh).

6.2.2 Convergence Behavior

The convergence curves for Problem 2 (Figure 4) exhibit markedly different characteristics compared to Problem 1, reflecting the substantially higher dimensionality (D = 384 vs. D = 20). MPA shows dramatic initial oscillation in the early iterations, likely due to the exploration-intensive Phase 1 of its search strategy in the high-dimensional space. SMA and PSO demonstrate more stable convergence trajectories, with SMA achieving consistent improvement throughout the optimization process. SCA and WOA converge to moderately lower cost values.

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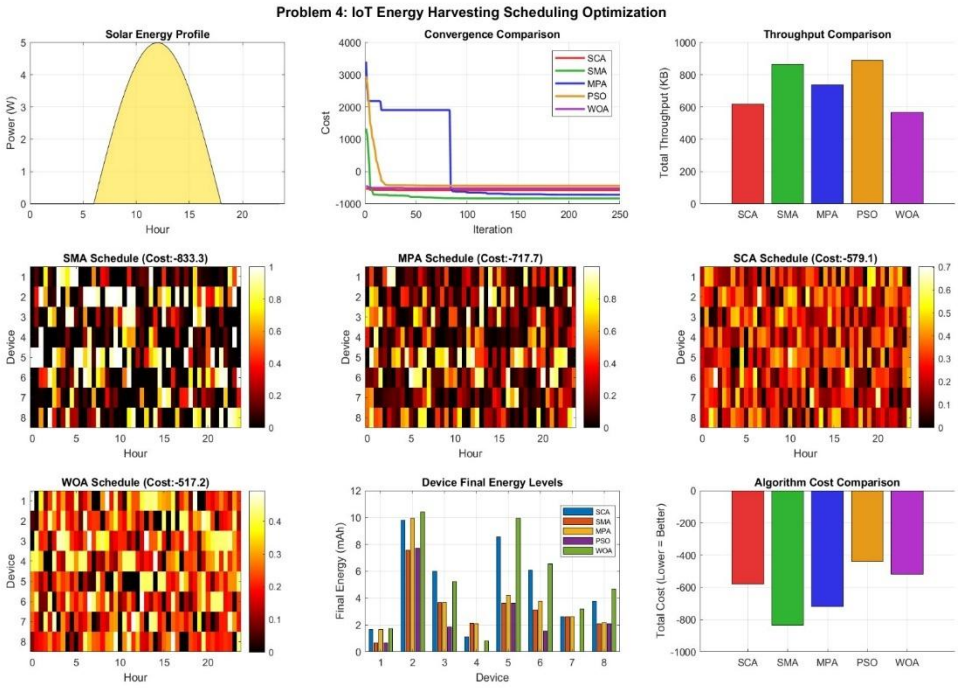

Figure 4. Main comparison results for the energy harvesting scheduling problem (Problem 2): solar profile, convergence curves, throughput comparison, scheduling heatmaps, device final energy levels, and algorithm cost comparison.

6.2.3 Battery Trajectory and Channel Analysis

Figure 5 illustrates the battery trajectories, channel quality map, and transmission activity versus solar availability for the best algorithm (SMA). Several important observations emerge from this analysis.

The battery trajectories show that all devices experience a gradual energy depletion during the nighttime hours (00:00–06:00) when no solar energy is available. Battery levels reach their minimum around 08:00–10:00, after which the accumulated solar energy begins to replenish the reserves. By the end of the 24-hour cycle, most devices maintain positive energy levels, indicating sustainable operation.

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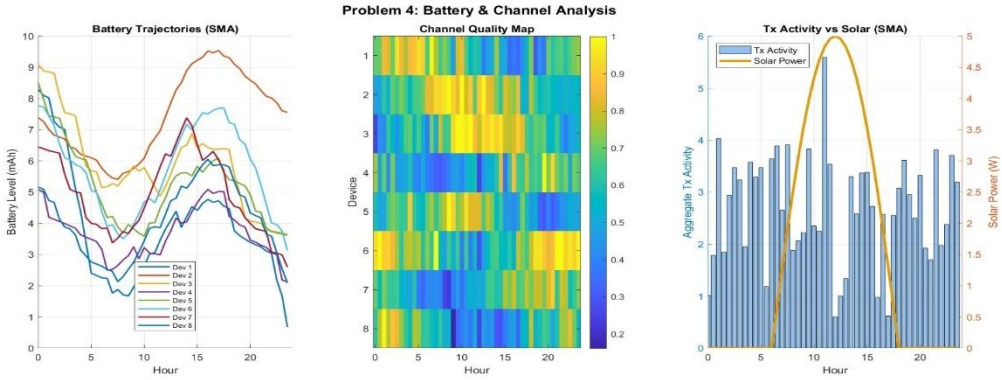

Figure 5. Battery trajectory analysis, channel quality heatmap, and transmission activity versus solar power overlay for the best algorithm (SMA) in Problem 2.

The transmission activity versus solar power overlay reveals that SMA's optimized schedule demonstrates intelligent energy-aware behavior: transmission activity is concentrated during periods of solar energy availability, with reduced activity during nighttime hours. This aligns with the intuitive strategy of transmitting when energy income is positive, thereby preserving battery reserves for essential nighttime operations.

6.2.4 Energy Efficiency Analysis

Figure 6 presents the energy efficiency analysis. SMA achieves the highest efficiency of 9.16 KB/mAh, indicating that it transmits the most data per unit of energy consumed. PSO follows with 8.69 KB/mAh, while MPA achieves 8.24 KB/mAh.

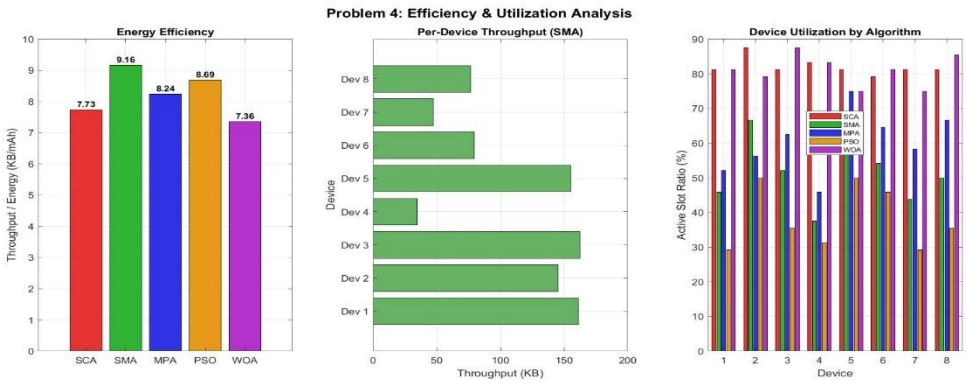

Figure 6. Energy efficiency comparison, per-device throughput breakdown, and device utilization by algorithm for Problem 2.

The per-device throughput breakdown reveals significant variation across devices, attributable to differences in channel quality, data rates, and battery capacities. Devices 1, 3, and 5 contribute the highest throughput, while Device 4 has the lowest contribution, likely due to a combination of lower data rate and less favorable channel conditions. The device utilization chart shows that SMA maintains a more balanced utilization across devices compared to other algorithms, suggesting a more equitable distribution of the transmission burden.

6.3 Cross-Problem Analysis

6.3.1 Algorithm Ranking Consistency

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Interestingly, SMA emerges as the top-performing algorithm in both problem domains. In the sensor placement configuration problem, SMA achieves the highest coverage of 94.4%, narrowly outperforming PSO (94.1%). In the energy harvesting scheduling problem, SMA attains the best cost value (–833.3) and the highest energy efficiency (9.16 KB/mAh). This consistent performance across both problems highlights the robustness and versatility of the adaptive weight mechanism employed by SMA.

The strong performance of SMA can be attributed to its dynamic adjustment of search intensity based on solution quality. In the lower-dimensional sensor placement problem (D = 20), this mechanism enables effective spatial exploration and exploitation. In the substantially higher-dimensional energy harvesting problem (D = 384), the same mechanism facilitates efficient navigation through the complex constraint landscape. PSO demonstrates competitive performance in both problems, ranking second in sensor placement and third in energy harvesting scheduling, confirming its reliability as a general-purpose optimizer. MPA achieves moderate performance in both domains but exhibits slower convergence, particularly in Problem 1. SCA and WOA consistently rank in the lower tiers, with SCA showing notably poor coverage in the sensor placement problem (80.2%) despite adequate stability.

6.3.2 Convergence Speed vs. Solution Quality

Table 4 summarizes the cross-problem performance characteristics of each algorithm.

Table 4. Cross-problem algorithm performance summary.

	SCA	SMA	MPA	PSO	WOA
P1 Rank	5	**1**	4	2	3
P2 Rank	4	**1**	2	3	5
Conv. Speed	Fast	Fast	Slow	Med	Med
Stability	Low	High	Med	High	Med

SMA emerges as the most consistently high-performing algorithm across both problems, achieving the top rank in both domains. PSO demonstrates strong and stable performance, ranking second and third, respectively. MPA shows competitive solution quality in the energy harvesting problem but is hampered by slower convergence, particularly in the sensor placement problem. WOA exhibits moderate performance with inconsistent rankings across the two problems. SCA, despite its rapid initial convergence, consistently produces lower-quality solutions, most notably in the sensor placement problem where it achieves the lowest coverage.

6.3.3 Practical Implications

From a practical standpoint, the findings of this study offer several actionable guidelines for IoT system designers:

For both sensor placement configuration and energy-aware scheduling problems, SMA is recommended as the primary optimization algorithm due to its consistently superior performance across both problem domains. Its adaptive weight mechanism provides an effective balance between exploration and exploitation regardless of problem dimensionality. PSO serves as a strong alternative, particularly for sensor placement problems with moderate

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dimensionality, where it achieves near-optimal coverage with stable convergence. For energy-aware scheduling problems with high dimensionality and complex constraint structures, MPA offers competitive performance as an alternative to SMA. SCA and WOA, while exhibiting faster initial convergence in certain cases, generally produce inferior solutions and are not recommended as primary choices for these IoT optimization problems.

7. Conclusion

This paper presented a comprehensive comparative study of five metaheuristic optimization algorithms—SCA, SMA, MPA, PSO, and WOA—applied to two critical IoT optimization problems: sensor placement configuration and energy harvesting scheduling.

The key findings are summarized as follows:

1. Sensor Placement Configuration: SMA achieved the highest area coverage of 94.4% with well-distributed sensor positions, closely followed by PSO with 94.1%. WOA and MPA attained moderate coverage values of 90.4% and 90.1%, respectively, while SCA exhibited the lowest performance at 80.2%. The adaptive weight mechanism of SMA proved particularly effective in balancing spatial exploration and exploitation in the 20-dimensional search space.

2. Energy Harvesting Scheduling: SMA attained the best throughput with a cost of –833.3 and an energy efficiency of 9.16 KB/mAh, demonstrating superior performance in the high-dimensional (384-D) search space. The optimized schedules exhibited intelligent energy-aware behavior, concentrating transmissions during periods of solar energy availability to maximize throughput while preserving battery sustainability.

3. Cross-Problem Insights: SMA consistently achieved the top rank across both problem domains, demonstrating its versatility and robustness as a general-purpose optimizer for IoT applications. PSO maintained competitive performance in both problems, confirming its reliability. MPA showed competitive results in the energy harvesting problem but was hampered by slower convergence in the sensor placement problem.

4. Convergence Characteristics: SMA and PSO exhibited the most stable convergence behavior across both problems. MPA showed characteristic phase-dependent convergence with slow initial progress but steady improvement in later iterations. SCA demonstrated rapid early convergence but converged to inferior solutions, while WOA exhibited moderate convergence stability.

7.1 Future Work

Several directions merit further investigation. First, multi-objective formulations that simultaneously optimize coverage, energy consumption, and network lifetime could provide more realistic problem models. Second, hybrid algorithms that combine the strengths of top-performing metaheuristics (e.g., SMA-PSO hybrids) may yield further improved performance beyond what either algorithm achieves individually. Third, adaptive parameter tuning mechanisms could enhance algorithm robustness across varying problem dimensions and constraint structures. Finally, experimental validation on real-world IoT testbeds would strengthen the practical applicability of the findings.

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A Comparative Study of Nature-Inspired Metaheuristic Algorithms for Solving the 0/1 Knapsack Problem

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ABSTRACT

The 0/1 Knapsack Problem (KP) is a classical NP-hard combinatorial optimization problem with significant practical relevance in resource allocation. As exact methods become computationally intractable for large-scale instances, metaheuristic algorithms offer viable alternatives for obtaining near-optimal solutions. This study presents a comparative analysis of five nature-inspired metaheuristic algorithms for solving the 0/1 KP: Whale Optimization Algorithm (WOA), Slime Mould Algorithm (SMA), Particle Swarm Optimization (PSO), Sine Cosine Algorithm (SCA), and Marine Predators Algorithm (MPA). A sigmoid transfer function is employed to map continuous search variables to binary decisions, while a penalty function handles capacity constraint violations.

The algorithms are evaluated on eight benchmark datasets with varying scales (10–100 items), capacity ratios (20%, 40%, 70%), and weight–value correlation structures. Each algorithm is executed with 50 agents over 300 iterations across 10 independent runs. The results, assessed through average ranking, demonstrate that SCA achieves the best overall performance (mean rank: 1.75), followed by SMA (1.88), MPA (2.50), PSO (3.88), and WOA (5.00). The superiority of SCA is attributed to its effective exploration–exploitation balance through sinusoidal fluctuation patterns in discrete search spaces. These findings are validated through convergence curves, boxplot distributions, heatmap visualizations, and radar chart comparisons.

Anahtar Kelimeler : Metaheuristic algorithms, 0/1 Knapsack Problem, Combinatorial optimization, Nature-inspired computing, Benchmark comparison

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1 Introduction

The 0–1 Knapsack Problem (KP) represents one of the most fundamental and challenging combinatorial optimization problems [1, 2]. Given a set of items characterized by weights and values, the objective is to select a subset of items that maximizes total value without exceeding a predefined capacity. Due to its NP-hard nature [3], exact solution methods become computationally impractical for large-scale instances.

Metaheuristic optimization algorithms have gained significant attention as effective alternatives for solving complex knapsack problems [4, 5]. Algorithms inspired by natural phenomena, such as swarm intelligence and evolutionary processes, offer flexible and scalable solution mechanisms [6]. However, their performance may vary significantly depending on problem characteristics such as dimensionality, correlation structure, and capacity constraints [7].

This study aims to provide a systematic and fair comparison of five widely used metaheuristic algorithms on multiple knapsack problem scenarios. Unlike many existing studies that focus on limited datasets, this work evaluates algorithmic behavior across eight diverse datasets, offering deeper insights into robustness and scalability.

2 Problem Formulation

The 0–1 Knapsack Problem is formulated as [1]:

$$\max \sum_{i=1}^{n} v_i x_i \qquad (1)$$

subject to

$$\sum_{i=1}^{n} w_i x_i \leq C, \quad x_i \in \{0,1\}, \qquad (2)$$

where vi and wi denote the value and weight of item i, respectively, and C is the knapsack capacity. To enable continuous metaheuristic optimization, a sigmoid transfer function is employed to map continuous decision variables into binary space [8]. Constraint violations are handled using a penalty-based fitness function [9]:

$$f(x) = -\text{TotalValue} + \lambda \max(0, \text{TotalWeight} - C), \qquad (3)$$

where λ is the penalty coefficient.

3 Metaheuristic Algorithms

Five population-based metaheuristic algorithms are investigated:

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- Whale Optimization Algorithm (WOA) [10]
- Slime Mould Algorithm (SMA) [11]
- Particle Swarm Optimization (PSO) [12]
- Sine Cosine Algorithm (SCA) [13]
- Marine Predators Algorithm (MPA) [14]

All algorithms operate under identical experimental conditions, including population size, iteration number, and search boundaries, ensuring a fair comparison [15].

4 Experimental Setup

Eight knapsack datasets are considered, representing diverse problem characteristics [7]:

- Small, medium, large, and very large-scale problems
- Strongly and weakly correlated item structures
- Tight and loose capacity constraints

Each algorithm is executed 10 independent runs per dataset using a population size of 50 and 300 iterations. Performance metrics include best value, average value, standard deviation, execution time, convergence behavior, and rank-based evaluation [15].

5 Results and Discussion

5.1 Knapsack Problem Instances

To comprehensively evaluate the performance of the considered metaheuristic algorithms, eight heterogeneous 0–1 knapsack problem instances were constructed. All datasets were implemented directly in the MATLAB code and are summarized below. The instances were designed to reflect variations in problem size, item correlation structure, and capacity tightness [7].

For each dataset, the knapsack capacity C was computed as:

$$C = \text{round}\left(\rho \sum_{i=1}^{n} w_i\right), \qquad (4)$$

where ρ denotes the capacity ratio.

5.1.1 DS1: Small Scale (10 Items)

DS1 represents a small-scale knapsack problem with a fixed and explicitly defined set of items. The item weights and values are deterministically specified as:

w = [5, 8, 3, 12, 7, 15, 10, 2, 6, 9],

v = [20, 45, 12, 60, 35, 80, 55, 8, 25, 40].

The capacity ratio is set to ρ = 0.40, resulting in a moderately constrained knapsack. This dataset serves as a baseline for evaluating algorithmic behavior on low-dimensional problems.

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5.1.2 DS2: Medium Scale (20 Items)

DS2 is a medium-scale instance consisting of 20 items with fixed weight and value assignments:

w = [12, 5, 18, 7, 23, 11, 3, 16, 9, 14, 6, 20, 8, 25, 4, 17, 10, 22, 13, 19],

v = [55, 30, 85, 42, 95, 50, 15, 72, 38, 65, 28, 90, 35, 100, 20, 78, 48, 88, 58, 82].

The capacity ratio is again fixed at ρ = 0.40. This dataset introduces higher dimensionality while maintaining deterministic item definitions.

5.1.3 DS3: Large Scale (50 Items)

DS3 is a large-scale knapsack problem consisting of 50 items. Item weights and values are randomly generated using a uniform distribution:

$$w_i \sim \mathcal{U}(1, 50), \quad v_i \sim \mathcal{U}(10, 200),$$

with a fixed random seed of rng(100) to ensure reproducibility. The capacity ratio is set to ρ = 0.40. This dataset is used to assess scalability and exploration capability in higher-dimensional search spaces.

5.1.4 DS4: Very Large Scale (100 Items)

DS4 extends the problem size to 100 items, representing a high-dimensional knapsack instance. The item parameters are generated as:

$$w_i \sim \mathcal{U}(1, 80), \quad v_i \sim \mathcal{U}(5, 300),$$

using the random seed rng(200). The capacity ratio remains ρ = 0.40. This dataset evaluates algorithm robustness and convergence behavior under very large search spaces.

5.1.5 DS5: Strongly Correlated Items (30 Items)

DS5 models a strongly correlated knapsack instance, where item values are approximately proportional to item weights [7]. Weights are generated as:

$$w_i \sim \mathcal{U}(5, 40),$$

and values are computed according to:

$$v_i = 3w_i + \epsilon_i, \quad \epsilon_i \sim \mathcal{U}(-2, 2),$$

with negative values prevented by truncation. A fixed random seed rng(300) is used, and the capacity ratio is set to ρ = 0.40. This dataset reflects scenarios where value-to-weight ratios are nearly uniform.

5.1.6 DS6: Weakly Correlated Items (30 Items)

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DS6 represents a weakly correlated instance in which item values are only loosely related to weights [7]. Weights are generated as:

$$w_i \sim \mathcal{U}(5, 40),$$

while values are defined by:

$$v_i = w_i + \eta_i, \quad \eta_i \sim \mathcal{U}(-30, 80),$$

with a lower bound enforced to ensure positive values. The dataset is generated using rng(400) and employs a capacity ratio of ρ = 0.40. This instance tests algorithm performance under noisy and irregular value distributions.

5.1.7 DS7: Tight Capacity (25 Items)

DS7 is designed to examine algorithm behavior under severe capacity constraints [2]. It consists of 25 items with:

$$w_i \sim \mathcal{U}(3, 35), \quad v_i \sim \mathcal{U}(10, 150),$$

generated using rng(500). A tight capacity ratio of ρ = 0.20 is employed, significantly restricting feasible solutions.

5.1.8 DS8: Loose Capacity (25 Items)

DS8 uses the same item generation scheme as DS7 but with a loose capacity constraint. Using rng(600), item weights and values follow:

$$w_i \sim \mathcal{U}(3, 35), \quad v_i \sim \mathcal{U}(10, 150),$$

while the capacity ratio is increased to ρ = 0.70. This dataset represents scenarios with high feasibility and emphasizes exploitation performance.

5.1.9 Convergence Analysis

Figure 1 presents the average convergence curves across all datasets. SCA and SMA demonstrate rapid convergence and stable exploitation behavior, consistent with the findings reported in [13] and [11]. MPA exhibits strong exploration in early stages but converges more slowly [14]. WOA consistently stagnates early, failing to approach competitive solutions, which aligns with the premature convergence issues noted in [10].

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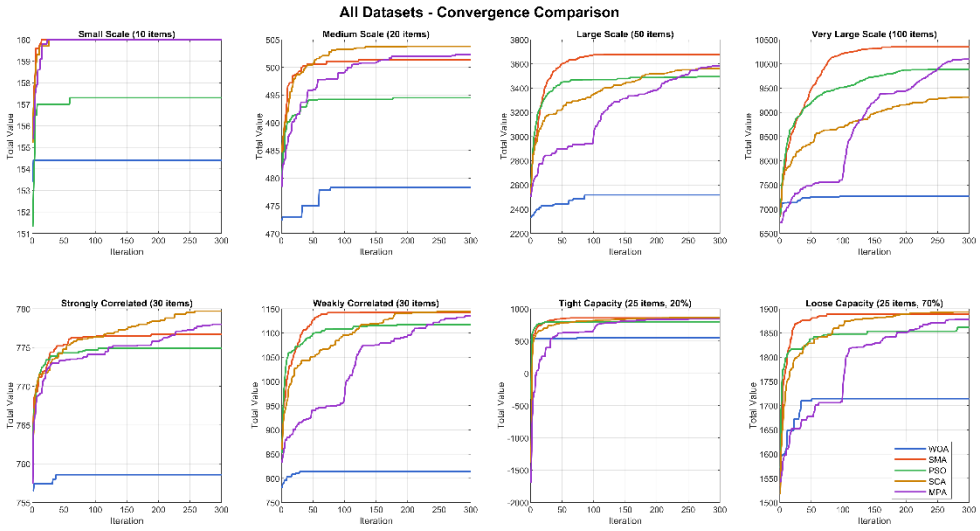

Figure 1: Convergence comparison across all datasets

5.1.10 Boxplot and Robustness Analysis

The boxplot distributions in Figure 2 reveal that SCA and SMA achieve both higher median values and lower variance. WOA displays large dispersion and inferior median performance, indicating instability and poor robustness. Statistical robustness analysis follows the methodology suggested in [15].

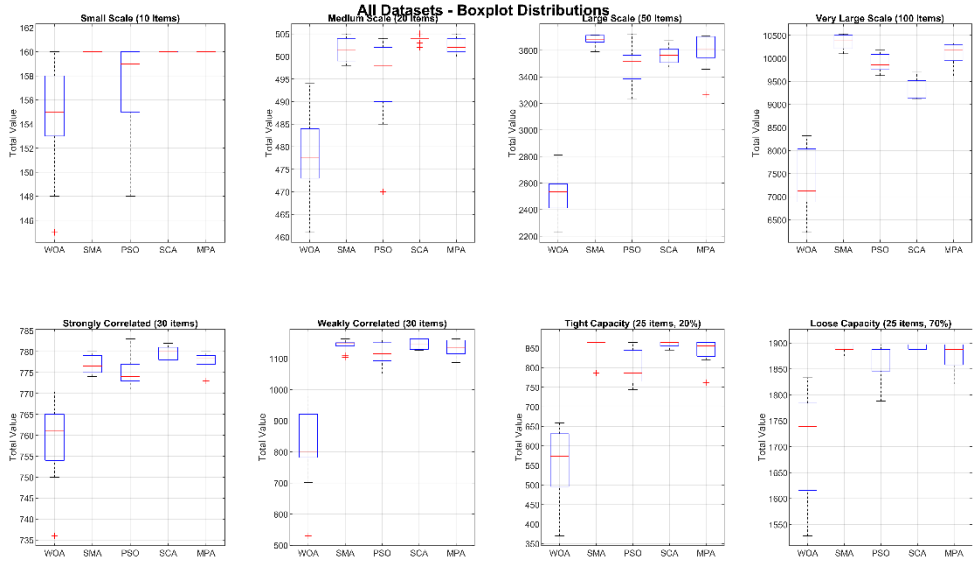

Figure 2: Boxplot distributions of solution quality

5.1.11 Scale and Capacity Sensitivity

Figures 3 and 4 illustrate algorithm performance under increasing problem size and varying capacity ratios. SCA maintains superior scalability, particularly in large-scale and very large-

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scale instances [13]. Under tight capacity constraints, SCA and SMA outperform other algorithms significantly.

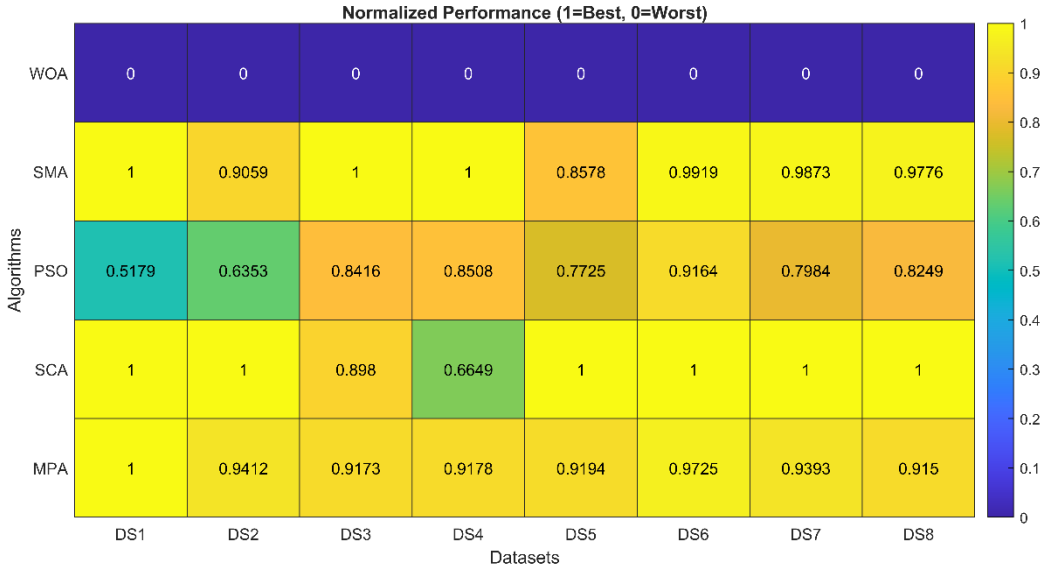

Figure 3: Problem scale vs algorithm performance

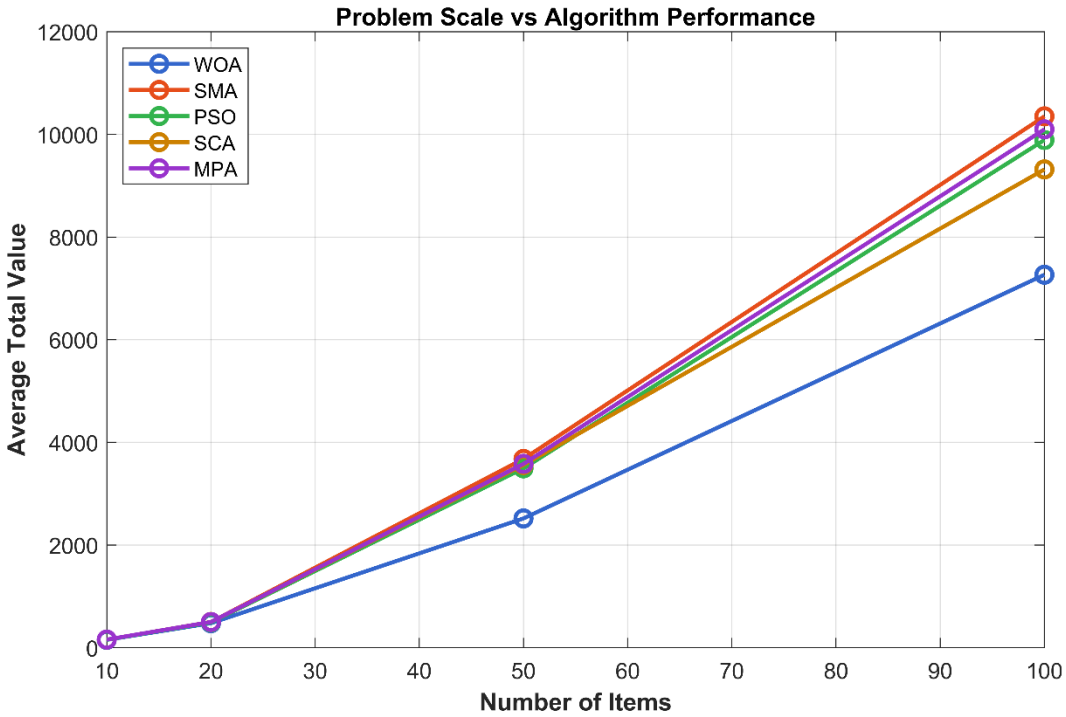

Figure 4: Capacity ratio vs algorithm performance

5.1.12 Ranking and Overall Performance

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The normalized heatmap in Figure 5 and the radar ranking diagram in Figure 6 provide a holistic comparison. SCA achieves first rank in the majority of datasets, followed by SMA and MPA. The overall average ranking confirms SCA as the best-performing algorithm, while WOA ranks last. The ranking methodology follows the Friedman test-based statistical comparison framework [15, 16].

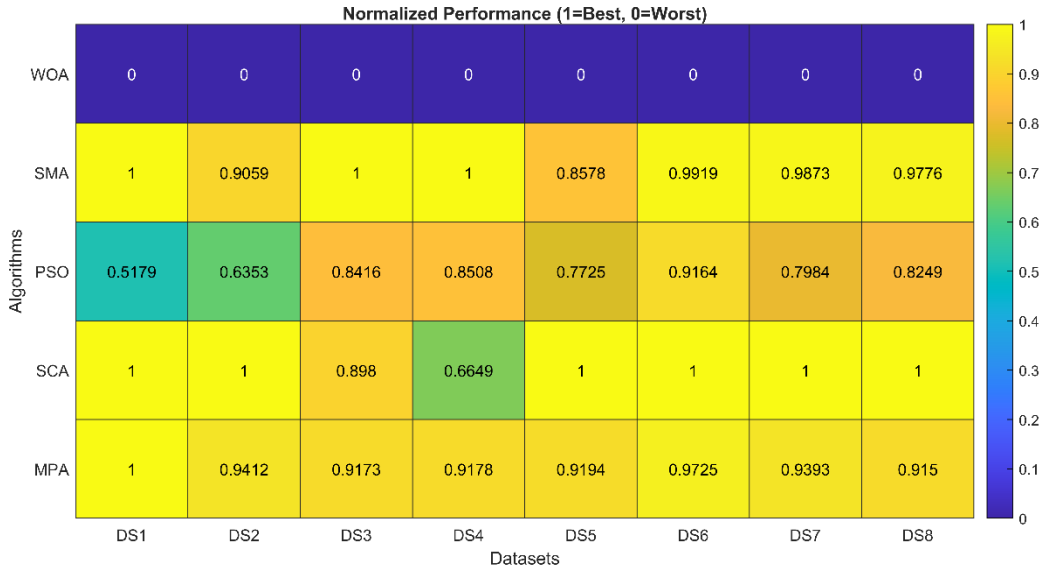

Figure 5: Normalized performance heatmap

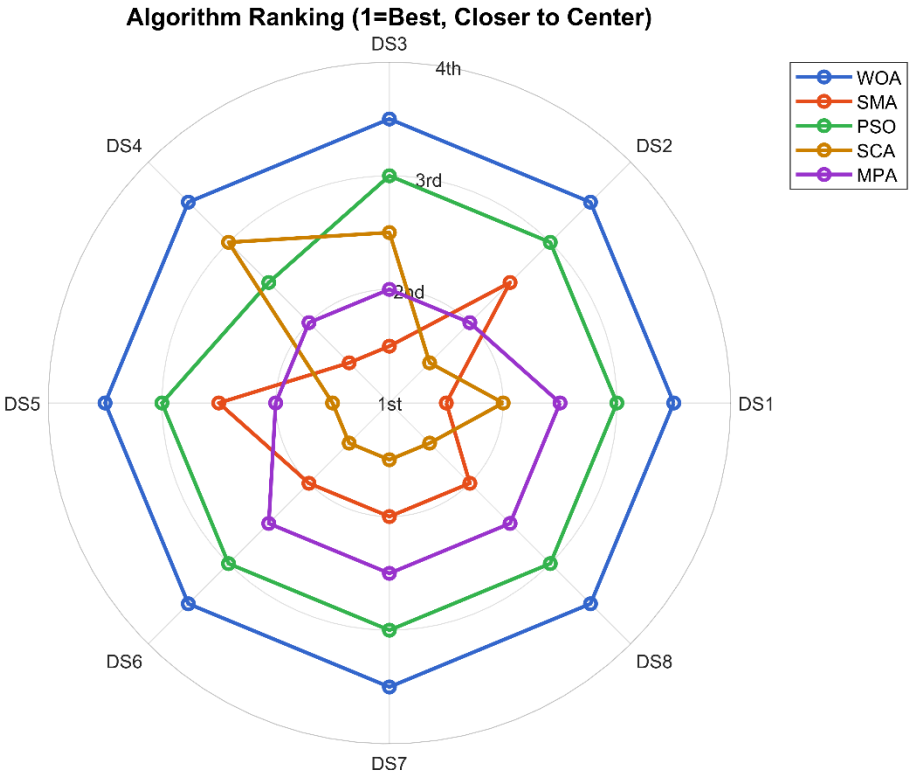

Figure 6: Algorithm ranking radar chart

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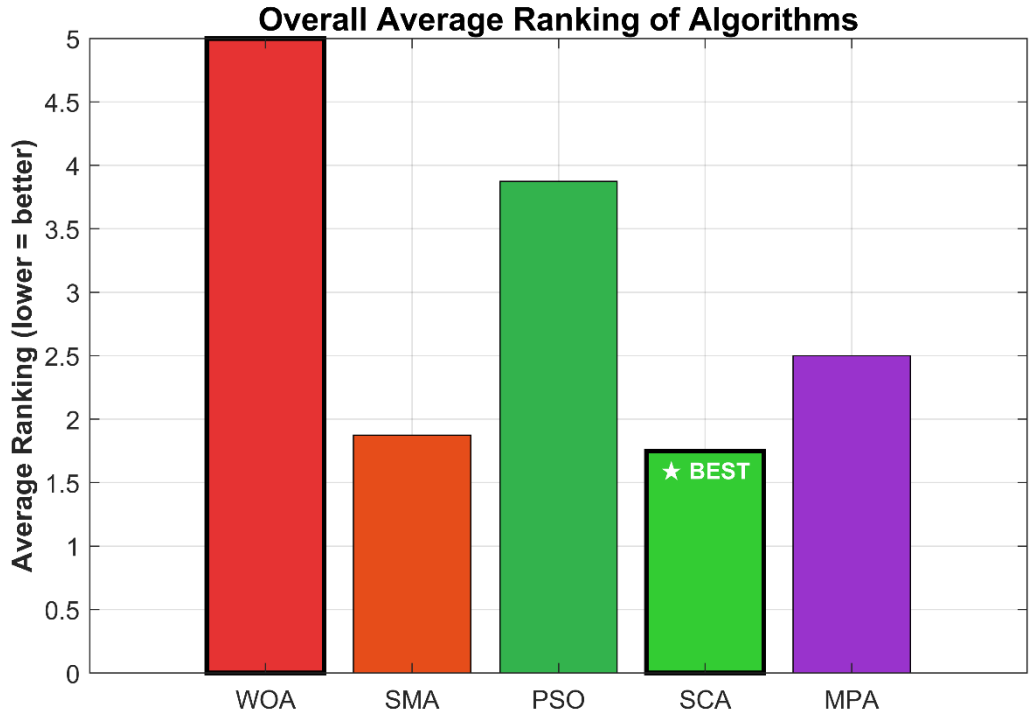

Figure 7: Overall average ranking of algorithms

6. Conclusion

This study presented a comprehensive comparative evaluation of five metaheuristic algorithms for solving diverse 0–1 knapsack problem scenarios. Based on extensive experimental analysis, the Sine Cosine Algorithm [13] consistently achieved superior solution quality, robustness, and scalability. SMA [11] and MPA [14] demonstrated competitive performance, while WOA [10] exhibited significant limitations. The findings highlight the importance of algorithm selection based on problem characteristics and provide valuable guidance for future knapsack optimization studies.

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STABILITY-VALUED NEUTROSOPHIC-POSITIVE DIRECTED SETS

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ABSTRACT

In this study, we first give the concepts of fuzzy sets, intuitionistic fuzzy sets, and neutrosophic sets. To make neutrosophic sets more effective and meaningful in practical applications, we introduce a hesitancy function based on the truth, falsity, and indeterminacy functions. Using these functions, we construct stability-valued neutrosophic positively directed sets through positive directions. Subsequently, desired operations on these sets are presented together with their properties.

Keywords: Neutrosophic sets, Stability-valued neutrosophic positive-directed sets, hesitancy function.

1. INTRODUCTION

In daily life, we frequently encounter problems involving uncertainty, such as concepts described as warm, cold, long short. In order to model such vagueness mathematically, many researchers have proposed various theoretical frameworks over time. One of the most significant of these is the fuzzy set theory introduced by Zadeh [15] in 1965. In this theory, a fuzzy set is characterized by a membership function that assigns to each element a degree of belonging within the interval [0,1]. Subsequently, to address situations where fuzzy sets were

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insufficient in representing uncertainty, Atanassov [2] extended this framework by introducing intuitionistic fuzzy sets in 1986. In addition to the membership function, this theory incorporates a non-membership function, allowing a more flexible representation of uncertainty. However, since the sum of the membership and non-membership degrees is still restricted to the interval [0,1] certain types of indeterminacy cannot be adequately modeled.

To overcome this limitation, Smarandache [9] introduced neutrosophic sets in 1998. In this framework, truth, falsity, and indeterminacy membership functions are defined independently, removing the restrictive condition present in previous models. This independence significantly increases the expressive power of the model in handling incomplete, inconsistent, and indeterminate information. Many studies have since been conducted on neutrosophic sets and their applications in various fields suc as [1,3,4-10,13,14].

Nevertheless, although hesitant-type functions have been considered within intuitionistic fuzzy set theory, a positively directed structure incorporating a hesitancy perspective has not been sufficiently developed in the neutrosophic sets. Therefore, in this study, in order to expand the theoretical scope of neutrosophic sets, stability-valued neutrosophic positively directed sets are constructed, and their fundamental concepts and properties are systematically developed.

2. PRELIMINARIES

Definition 1. [15] Let X be a non-empty set. A fuzzy set denoted by A on X and defined by the membership function $\mu_A: X \to [0,1]$ is defined as

$$A = \{\langle x, \mu_A(x)\rangle : x \in X\}$$

Definition 2. [2] Let X be a non-empty set and x∈X. Then, on X , a intuitionistic fuzzy set I with $T_I(x) \to [0,1]$ as a membership function and $F_I(x) \to [0,1]$as a non-member function, is defined as follows,

$$I = \{\langle x, T_I(x), F_I(x) >: x \in X\}$$

where $0 \leq T_I(x) + F_I(x) \leq 1$ for every $x \in X$.

Definition 3. [12] Let X be a non-empty set and $x \in X$. Then, a neutrosophic set A is defined as

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$$A = \{< u, \left(T_A(x), I_A(x), F_A(x)\right) >: x \in E,\ T_A(x), I_A(x), F_A(x) \in [0,1]\}.$$

where $T_A(x) \to [0,1]$ is the truth-membership function, $I_A(x) \to [0,1]$ is the indeterminacy-membership function, and $F_A(x) \to [0,1]$ is the falsity-membership function such that $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$.

Definition 4.[11] Let $A_1 = \{< x, \left(T_1(x), I_1(x), F_1(x)\right) >: x \in X,\ T_1(x), I_1(x), F_1(x) \in [0,1]\}$, $A_2 = \{< u, \left(T_2(x), I_2(x), F_2(x)\right) >: x \in X,\ T_2(x), I_2(x), F_2(x) \in [0,1]\}$ be two neutrosophic sets. Then,

1. $A_1 \widetilde{\oplus} A_2 = \{\langle x, T_1(x) + T_2(x) - T_1(x).T_2(x), I_1(x).I_2(x), F_1(x).F_2(x)\rangle : x \in X\}$ dir.
2. $A_1 \widetilde{\otimes} A_2 = \{\langle x, T_1(x).T_2(x), I_1(x) + I_2(x) - I_1(x).I_2(x), F_1(x) + F_2(x) - F_1(x).F_2(x)\rangle : x \in X\}$
3. $\lambda A_1 = \{\langle x, 1 - \left(1 - T_1(x)\right)^{\lambda}, I_1(x)^{\lambda}, F_1(x)^{\lambda}\rangle : x \in X\}$
4. $A_1^{\lambda} = \{\langle x, T_1(x)^{\lambda}, 1 - \left(1 - I_1(x)\right)^{\lambda}, 1 - \left(1 - F_1(x)\right)^{\lambda}\rangle : x \in X\}$.

3. STABILITY-VALUED NEUTROSOPHIC POSITIVE DIRECTED SETS

In this section, we introduce stability-valued neutrosophic positive directed sets and examine some of their properties. The concepts in this section are derived from existing studies on fuzzy sets, intuitionistic fuzzy sets and neutrosophic sets in [3-14]

Definition 5. Let X be a non-empty set and $x \in X$. Then, a stability-valued neutrosophic negative directed sets (SvND) Υ on U are characterized by $T_A(x) \to [0,1]$ truth-membership function, $I_A(x) \to [0,1]$ indeterminacy-membership function, $F_A(x) \to [0,1]$ falsity-membership function and $\Pi_A(x) \to [0,1]$ hesitant-membership function and defined as

$$\Upsilon = \{< u, \left(1 - I(u), T(u), F_A(u), \Pi^+(u)\right) >: u \in U\}.$$

where $\Pi^+(u) = T(u).\Pi(u)$ such that $\Pi_A(u) = \left|1 - \left(T_A(u) + F_A(u)\right)\right|$ dir. Burada, $\Pi^+(u)$ is the positive-directed falsity-membership value of the element u.
Note that the collection of all SvND sets on U is denoted by SvND(U).

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Definition 6. Let $\Upsilon_1 = \{< u, \left(1 - I_1(u), T_1(u), F_1(u), \Pi_1^+(u)\right) >: u \in U\}$,

$\Upsilon_2 = \{< u, \left(1 - I_2(u), T_2(u), F_2(u), \Pi_2^+(u)\right) >: u \in U\} \in SvND(U)$. Then,

O halde,

1. $\Upsilon_1 \tilde{+} \Upsilon_2 = \{< x, \left(1 - I_1(u)\right) + \left(1 - I_2(u)\right) - \left(1 - I_1(u)\right)(1 - I_2(u), T_1(u) + T_2(u) - \left(T_1(u)T_2(u)\right), F_1(u)F_2(u), \Pi_1^+(u) + \Pi_2^+(u) - \left(\Pi_1^+(u)\Pi_2^+(u)\right) >: u \in U\}$

2. $\Upsilon_1 \tilde{\times} \Upsilon_2 = \{< x, \left(1 - I_1(u)\right)\left(1 - I_2(u)\right), \left(T_1(u)T_2(u)\right), F_1(u) + F_2(u) - \left(F_1(u)F_2(u)\right), \Pi_1^+(u)\Pi_2^+(u) >: u \in U\}$

3. $\lambda\Upsilon_1 = \{< x, 1 - \left(1 - \left(1 - I_1(u)\right)\right)^\lambda, 1 - \left(1 - T_1(u)\right)^\lambda, F_1(u)^\lambda, 1 - (1 - \Pi_1^+(u))^\lambda >: u \in U\}$

4. $\Upsilon_1^\lambda = \{< x, \left(1 - I_1(u)\right)^\lambda, T_1(u)^\lambda, 1 - \left(1 - F_1(u)\right)^\lambda, \left(\Pi_1^+(u)\right)^\lambda >: u \in U\}$

Definition 7. Let $\Upsilon = \{< u, \left(1 - I(u), T(u), F(u), \Pi^+(u)\right) >: u \in U\} \in SvND(U)$. Then,

1. The 1. score value of Υ, denoted by $M_1(\Upsilon)$, is defined as follows:

$$M_1(\Upsilon) = \frac{\left[2 + \left(1 - I(u)\right) + T(u) + \pi^+(u) - F(u)\right]}{4}$$

2. The 2. score value of Υ, denoted by $M_2(\Upsilon)$, is defined as follows:

$$M_2(\Upsilon) = \frac{\left[\left(1 - I(u)\right).\left(2 + T(u) + \pi^+(u) - F(u)\right)\right]}{3}$$

3. The 3. score value of Υ, denoted by $M_3(\Upsilon)$, is defined as follows:

$$M_3(\Upsilon) = \frac{1 + \left[\left(1 - I(u)\right).T(u).\pi^+(u) - \left(1 - I(u)\right).F(u)\right]}{2}$$

Also, for $\Upsilon_1 = \{< u, \left(1 - I_1(u), T_1(u), F_1(u), \Pi_1^+(u)\right) >: u \in U\}$, $\Upsilon_2 = \{< u, \left(1 - I_2(u), T_2(u), F_2(u), \Pi_2^+(u)\right) >: u \in U\} \in$ SvND(U), $M_i(\Upsilon_1)$ and $M_i(\Upsilon_2)$ be the i-th (i=1,2,3) score values of for Υ_1 and Υ_2, respectively.

Then, the comparison between Υ_1 and Υ_2, is made as follows:

1. $M_i(\Upsilon_1) < M_i(\Upsilon_1)$ ise $\Upsilon_1 < \Upsilon_1$
2. $M_i(\Upsilon_1) = M_i(\Upsilon_1)$ ise $\Upsilon_1 = \Upsilon_1$

From now on, for the sake of brevity, we use $\langle (1 - I), T, F, \Pi^+ \rangle$ instead of $\langle x, (1 - I(x), T(x), F(x), \Pi^+(x) \rangle$.

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Definition 8. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^+ \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then, Then, the weighted SvND arithmetic aggregation operatör denoted by $s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ and defined as;

$$s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) = \oplus_{i=1}^{n} w_i \Upsilon_i$$

Based Definition 6, the operatör $s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ is given as;

Theorem 9. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^+ \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then, Then, the weighted SvND arithmetic aggregation operatör $s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ calculated as;

$s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) = \langle 1 - \otimes_{i=1}^{n} \big(1-(1-I_i)\big)^{w_i}, 1 - \otimes_{i=1}^{n} (1-T_i)^{w_i}, \otimes_{i=1}^{n} F_i^{w_i}, 1 - \otimes_{i=1}^{n} (1-\Pi_i^+)^{w_i} \rangle$

Example 10. Let $\Upsilon_1 = \langle 0.1,0.3,0.7,0.3 \rangle$, $\Upsilon_2 = \langle 0.2,0.4,0.6,0.4 \rangle$, $\Upsilon_3 = \langle 0.1,0.1,0.9,0.1 \rangle$, $\Upsilon_4 = \langle 0.1,0.3,0.7,0.3 \rangle$, $\Upsilon_5 = \langle 0.4,0.2,0.6,0.36 \rangle \in$ SvND(U) and $w = (0.1,0.2,0.4,0.1,0.2)$.

Then, $s_A^w(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5)$ is found as;

$$\begin{aligned} s_A^w(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5) &= \langle 1 - \otimes_{i=1}^{5} \big(1-(1-I_i)\big)^{w_i}, 1 - \otimes_{i=1}^{5} (1-T_i)^{w_i}, \otimes_{i=1}^{5} F_i^{w_i}, 1 - \otimes_{i=1}^{5} (1-\Pi_i^+)^{w_i} \rangle \\ &= \langle 1 - (0.9^{0.1} 0.8^{0,2} 0, 9^{0.4} 0.9^{0.1} 0.6^{0.2}), 1 - (0.7^{0.1} 0.6^{0.2} 0.9^{0.4} 0.7^{0.1} 0.8^{0.2}), \\ &\quad 0.7^{0.1} 0.6^{0.2} 0.9^{0.4} 0.7^{0.1} 0.6^{0.2}, 1 - (0.7^{0.1} 0.6^{0.2} 0.9^{0.4} 0.7^{0.1} 0.64^{0.2}) \rangle \\ &= \langle 0.189424, 0.229159, 0.727741, 0.262804 \rangle \end{aligned}$$

Definition 11. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^+ \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then, Then, the weighted SvND geometric aggregation operatör denoted by $s_G^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ and defined as;

$$s_G^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) = \otimes_{i=1}^{n} \Upsilon_i^{w_i}$$

Based Definition 6, the operatör $s_G^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ is given as;

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Theorem 12. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^+ \rangle$, $i \in I_n = \{1,2,\dots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \dots, w_n)$ such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then, Then, the weighted SvND geometric aggregation operator $s_G^w(\Upsilon_1, \Upsilon_2, \dots, \Upsilon_n)$ calculated as;

$$s_G^w(\Upsilon_1, \Upsilon_2, \dots, \Upsilon_n) = \langle \otimes_{i=1}^{n} (1-I_i)^{w_i}, \otimes_{i=1}^{n} (T_i)^{w_i}, 1 - \otimes_{i=1}^{n} (1-F_i)^{w_i}, \otimes_{i=1}^{n} (\Pi_i^+)^{w_i} \rangle$$

Example 13. Let $\Upsilon_1 = \langle 0.1,0.4,0.6,0.5 \rangle$, $\Upsilon_2 = \langle 0.2,0.4,0.1,0.1 \rangle$, $\Upsilon_3 = \langle 0.4,0.6,0.2,0.36 \rangle$, $\Upsilon_4 = \langle 0.1,0.3,0.7,0.3 \rangle$, $\Upsilon_5 = \langle 0.2,0.4,0,0.4 \rangle \in$ SvND(U) and $w = (0.1,0.2,0.4,0.1,0.2)$.

Then, $s_G^w(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5)$ is found as;

$$\begin{aligned} s_G^w(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5) &= \langle \otimes_{i=1}^{5} (1-I_i)^{w_i}, \otimes_{i=1}^{5} (T_i)^{W_i}, 1 - \otimes_{i=1}^{5} (1-F_i)^{w_i}, \otimes_{i=1}^{5} (\Pi_i^+)^{w_i} \rangle \\ &= \langle 0.730037,0.457091,0.27556,0.288763 \rangle \end{aligned}$$

Definition 14. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^+ \rangle$, $i \in I_n = \{1,2,\dots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \dots, w_n)$ be a weighted vector such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$ and $v = (v_1, v_2, \dots, v_n)$ be a position such that $v_j \in [0,1]$, $\sum_{j=1}^{n} v_j = 1$. Then, the weighted hybrid ordered arithmetic operator denoted by $s_{OHA}^q(\Upsilon_1, \Upsilon_2, \dots, \Upsilon_n)$ and defined as;

$$s_{OHA}^q(\Upsilon_1, \Upsilon_2, \dots, \Upsilon_n) = \sqrt[q]{\bigoplus_{k=1}^{n} w_k (B_k)^q}$$

Here and $\widehat{B_k}$ denotes the k-th largest $B_j = n.V_j.\Upsilon_j$.

Also, we have based on Definition 6 as;

Theorem 15. . Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^+ \rangle$, $i \in I_n = \{1,2,\dots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \dots, w_n)$ be a weighted vector such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$ and $v = (v_1, v_2, \dots, v_n)$ be a position such that $v_j \in [0,1]$, $\sum_{j=1}^{n} v_j = 1$. Then, the weighted hybrid ordered arithmetic operator $s_{OHA}^q(\Upsilon_1, \Upsilon_2, \dots, \Upsilon_n)$ calculated as;

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$$
\begin{aligned}
s_{OHA}^{q}(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) &= \sqrt[q]{\oplus_{k=1}^{n} w_k (B_k)^q} \\
s_A^{w}(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) &= \oplus_{k=1}^{n} w_k B_k \\
&= \langle 1 - \otimes_{k=1}^{n} \left(1 - (1 - I_k)\right)^{w_k}, 1 - \otimes_{k=1}^{n} (1 - T_k)^{W_k}, \otimes_{k=1}^{n} F_k^{w_k}, 1 - \otimes_{k=1}^{n} (1 - \Pi_k^{+})^{w_k} \rangle \\
B_k &= \left((1 - I_k), T_k, F_k, \Pi_k^{+}\right) \\
(B_k)^q &= \langle (1 - I_k)^q, (T_k)^q, 1 - (1 - F_k)^q, (\Pi_k^{+})^q \rangle \\
s_{OHA}^{q} &= \langle 1 - \otimes_{k=1}^{n} (1 - (1 - I_k)^q)^{w_k}, 1 - \otimes_{k=1}^{n} \left(1 - T_k^q\right)^{W_k}, \otimes_{k=1}^{n} (1 - (1 - F_k)^q)^{w_k}, \\
&\quad 1 - \otimes_{k=1}^{n} (1 - (\Pi_k^{+})^q)^{w_k} \rangle \\
s_{OHA}^{q}(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) &= \langle (1 - \otimes_{k=1}^{n} (1 - (1 - I_k)^q)^{w_k})^{1/q}, \left(1 - \otimes_{k=1}^{n} \left(1 - T_k^q\right)^{W_k}\right)^{1/q}, \\
&\quad (\otimes_{k=1}^{n} (1 - (1 - F_k)^q)^{w_k})^{1/q}, (1 - \otimes_{k=1}^{n} ((1 - (\Pi_k^{+})^q)^{w_k})^{1/q} \rangle
\end{aligned}
$$

4

4. Conclusion

In this study, we have extended the theoretical framework of neutrosophic sets by introducing stability-valued neutrosophic positively directed sets. By incorporating a hesitancy function derived from the truth, falsity, and indeterminacy membership functions, the proposed structure provides a more comprehensive and flexible representation of uncertainty. This approach enhances the expressive power of neutrosophic modeling, particularly in situations involving incomplete, inconsistent, or indeterminate information. Furthermore, we have defined several operational laws for stability-valued neutrosophic positively directed sets and investigated their fundamental properties. These operators preserve the structural characteristics of the proposed sets and enable consistent aggregation and comparison processes.

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ON STABILITY-VALUED NEUTROSOPHIC-NEGATIVE DIRECTED SETS AND ITS APPLICATIONS

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ABSTRACT
In this study, neutrosophic sets and their generalizations are examined in detail. Subsequently, the limitations of neutrosophic sets are identified, and by taking the hesitant degree in intuitionistic fuzzy sets into consideration, stability-valued neutrosophic negatively directed sets are constructed through negative directions. Furthermore, the distance measure concept available in the literature is extended to this new structure. Finally, a multi-criteria decision-making method based on stability-valued neutrosophic negatively directed sets is proposed.
Keywords: Neutrosophic sets, Stability-valued neutrosophic negative-directed sets, distance function, decision making

4. INTRODUCTION

Classical logic requires definite judgments when modeling an event; that is, a proposition must be either true or false. However, this strict framework becomes insufficient when dealing with real-life problems involving uncertainty. For instance, when attempting to model whether a football team “played well” in a match, it is not possible to reach a solution based on a sharp true–false judgment. To model such uncertainty, Zadeh[13] developed fuzzy set theory by introducing a membership function taking continuous values between 0 and 1. According to this theory, the degree to which a football team played well may be expressed as 0.7. However,

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in this case, the degree of not playing well is not necessarily 0.3, since uncertainty is not strictly complementary. To overcome this limitation, Atanassov[2] proposed intuitionistic fuzzy set theory. In this framework, both membership and non-membership functions are defined, with the restriction that their sum must lie within the interval [0,1]. For example, the degree of not playing well may be chosen as 0.2; in this case, the hesitation (indeterminacy) degree, which completes the sum to 1, becomes 0.1. Furthermore, if factors such as the location of the match or the presence of spectators are taken into account, it may be necessary to consider changes under different conditions. By incorporating the concept of independence (also referred to as indeterminacy) and allowing three functions—truth, falsity, and independence—defined independently on the interval [0,1], Smarandache[10] developed neutrosophic set theory. Over time, detailed studies such as [1,3-7,9,11,12] have been conducted on these theories. In this study, the construction of the truth and falsity functions naturally gives rise to a hesitation-like component similar to that in intuitionistic fuzzy sets. Since this value may sometimes play a significant role, in this study stability-valued neutrosophic negatively directed sets are constructed so that this component can have a negative influence on the decision-making process.

5. PRELIMINARIES

Definition 1.[13]Let X be a non-empty set. A fuzzy set denoted by A on X and defined by the membership function $\mu_A: X \to [0,1]$ is defined as

$$A = \{\langle x, \mu_A(x)\rangle : x \in X\}$$

Definition 2. [2] Let X be a non-empty set and x∈X. Then, on X , a intuitionistic fuzzy set I with $T_I(x) \to [0,1]$ as a membership function and $F_I(x) \to [0,1]$as a non-member function, is defined as follows,

$$I = \{\langle x, T_I(x), F_I(x) >: x \in X\}$$

where $0 \leq T_I(x) + F_I(x) \leq 1$ for every $x \in X$.

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Definition 3. [12] Let X be a non-empty set and $x \in X$. Then, a neutrosophic set A is defined as

$$A = \{< u, \left(T_A(x), I_A(x), F_A(x)\right) >: x \in E,\ T_A(x), I_A(x), F_A(x) \in [0,1]\}.$$

where $T_A(x) \to [0,1]$ is the truth-membership function, $I_A(x) \to [0,1]$ is the indeterminacy-membership function, and $F_A(x) \to [0,1]$ is the falsity-membership function such that $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$.

Definition 4.[8] Let $A_1 = \{< x, \left(T_1(x), I_1(x), F_1(x)\right) >: x \in X,\ T_1(x), I_1(x), F_1(x) \in [0,1]\}$, $A_2 = \{< u, \left(T_2(x), I_2(x), F_2(x)\right) >: x \in X,\ T_2(x), I_2(x), F_2(x) \in [0,1]\}$ be two neutrosophic sets. Then,

5. $A_1 \widetilde{\oplus} A_2 = \{\langle x, T_1(x) + T_2(x) - T_1(x).T_2(x), I_1(x).I_2(x), F_1(x).F_2(x)\rangle : x \in X\}$ dir.
6. $A_1 \widetilde{\otimes} A_2 = \{\langle x, T_1(x).T_2(x), I_1(x) + I_2(x) - I_1(x).I_2(x), F_1(x) + F_2(x) - F_1(x).F_2(x)\rangle : x \in X\}$
7. $\lambda A_1 = \{\langle x, 1 - \left(1 - T_1(x)\right)^{\lambda}, I_1(x)^{\lambda}, F_1(x)^{\lambda}\rangle : x \in X\}$
8. $A_1^{\lambda} = \{\langle x, T_1(x)^{\lambda}, 1 - \left(1 - I_1(x)\right)^{\lambda}, 1 - \left(1 - F_1(x)\right)^{\lambda}\rangle : x \in X\}$.

6. STABILITY-VALUED NEUTROSOPHIC NEGATIVE DIRECTED SETS

In this section, we introduce stability-valued neutrosophic negative directed sets and examine some of their properties. The concepts in this section are derived from existing studies on neutrosophic sets in [1,12].

Definition 5. Let X be a non-empty set and $x \in X$. Then, a stability-valued neutrosophic negative directed sets (SvND) Υ on U are characterized by $T_A(x) \to [0,1]$ truth-membership function, $I_A(x) \to [0,1]$ indeterminacy-membership function, $F_A(x) \to [0,1]$ falsity-membership function and $\Pi_A(x) \to [0,1]$ hesitant-membership function and defined as

$$\Upsilon = \{< u, \left(1 - I(u), T(u), F_A(u), \Pi^{-}(u)\right) >: u \in U\}.$$

where $\Pi^{+}(u) = F(u).\Pi(u)$ such that $\Pi_A(u) = \left|1 - \left(T_A(u) + F_A(u)\right)\right|$

In here, $\Pi^{+}(u)$ is the negative-directed falsity-membership value of the element u.

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Note that the collection of all SvND sets on U is denoted by SvND(U).

Definition 6. Let $\Upsilon_1 = \{< u, \left(1 - I_1(u), T_1(u), F_1(u), \Pi_1^-(u)\right) >: u \in U\}$,

$\Upsilon_2 = \{< u, \left(1 - I_2(u), T_2(u), F_2(u), \Pi_2^-(u)\right) >: u \in U\} \in SvND(U)$. Then,

1. $\Upsilon_1 \tilde{+} \Upsilon_2 = \{< x, \{\left(1 - I_1(u)\right) + \left(1 - I_2(u)\right) - \left(1 - I_1(u)\right)(1 - I_2(u)\}, \{T_1(u) + T_2(u) - \left(T_1(u)T_2(u)\right)\}, \{F_1(u)F_2(u)\}, \{\Pi_1^-(u)\Pi_2^-(u)\} >: u \in U\}$
2. $\Upsilon_1 \tilde{\times} \Upsilon_2 = \{< x, \{\left(1 - I_1(u)\right)\left(1 - I_2(u)\right)\}, \{\left(T_1(u)T_2(u)\right)\}, \{F_1(u) + F_2(u) - \left(F_1(u)F_2(u)\right)\}, \{\Pi_1^-(u) + \Pi_2^-(u) - \left(\Pi_1^-(u)\Pi_2^-(u)\right)\} >: u \in U\}$
3. $\lambda\Upsilon_1 = \{< x, \{1 - \left(1 - \left(1 - I_1(u)\right)\right)^{\lambda}\}, \{1 - \left(1 - T_1(u)\right)^{\lambda}\}, \{F_1(u)^{\lambda}, \{\Pi_1^-(u))^{\lambda}\} >: u \in U\}$
4. $\Upsilon_1^{\lambda} = \{< x, \{\left(1 - I_1(u)\right)^{\lambda}\}, \{T_1(u)^{\lambda}\}, \{1 - \left(1 - F_1(u)\right)^{\lambda}, \{1 - \left(1 - \Pi_1^-(u)\right)^{\lambda}\} >: u \in U\}$

Definition 7. Let $\Upsilon = \{< u, \left(1 - I(u), T(u), F(u), \Pi^-(u)\right) >: u \in U\} \in SvND(U)$. Then

1. The 1. score value of Υ, denoted by $M_1(\Upsilon)$, is defined as follows:
$$M_1(\Upsilon) = \frac{\left[2 + \left(1 - I(u)\right) + T(u) - F(u) - \pi^-(u)\right]}{4}$$
2. The 2. score value of Υ, denoted by $M_2(\Upsilon)$, is defined as follows:
$$M_2(\Upsilon) = \frac{\left[\left(1 - I(u)\right).\left(2 + T(u) - F(u) - \pi^-(u)\right)\right]}{3}$$
3. The 3. score value of Υ, denoted by $M_3(\Upsilon)$, is defined as follows:
$$M_3(\Upsilon) = \frac{1 + \left[\left(1 - I(u)\right).T(u) - \left(1 - I(u)\right).F(u).\pi^-(u)\right]}{2}$$

Also, for $\Upsilon_1 = \{< u, \left(1 - I_1(u), T_1(u), F_1(u), \Pi_1^-(u)\right) >: u \in U\}$, $\Upsilon_2 = \{< u, \left(1 - I_2(u), T_2(u), F_2(u), \Pi_2^-(u)\right) >: u \in U\} \in$ SvND(U), $M_i(\Upsilon_1)$ and $M_i(\Upsilon_2)$ be the i-th (i=1,2,3) score values of for Υ_1 and Υ_2, respectively.

Then, the comparison between Υ_1 and Υ_2, is made as follows:

3. $M_i(\Upsilon_1) < M_i(\Upsilon_1)$ ise $\Upsilon_1 < \Upsilon_1$
4. $M_i(\Upsilon_1) = M_i(\Upsilon_1)$ ise $\Upsilon_1 = \Upsilon_1$

From now on, for the sake of brevity, we use $\langle (1 - I), T, F, \Pi^- \rangle$ instead of $\langle x, (1 - I(x), T(x), F(x), \Pi^-(x) \rangle$.

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Definition 8. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^- \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then, Then, the weighted SvND arithmetic aggregation operatör denoted by $s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ and defined as;

$$s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) = \oplus_{i=1}^{n} w_i \Upsilon_i$$

Based Definition 6, the operatör $s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ is given as;

Theorem 9. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^- \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then, Then, the weighted SvND arithmetic aggregation operatör $s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ calculated as;

$$s_A^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) = \langle 1 - \otimes_{i=1}^{n} \left(1-(1-I_i)\right)^{w_i}, 1 - \otimes_{i=1}^{n} (1-T_i)^{w_i}, \otimes_{i=1}^{n} F_i^{w_i}, \otimes_{i=1}^{n} (\Pi_i^-)^{w_i} \rangle$$

Example 10. Let $\Upsilon_1 = \langle 0.1,0.3,0.7,0 \rangle, \Upsilon_2 = \langle 0.2,0.4,0.6,0 \rangle$, $\Upsilon_3 = \langle 0.1,0.1,0.9,0 \rangle, \Upsilon_4 = \langle 0.1,0.3,0.7,0 \rangle,$, $\Upsilon_5 = \langle 0.4,0.2,0.6,0.12 \rangle \in$ SvND(U) and $w = (0.1,0.2,0.4,0.1,0.2)$.

Then, $s_A^w(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5)$ is found as;

$$\begin{aligned} s_A^w(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5) &= \langle 1 - \otimes_{i=1}^{5} \left(1-(1-I_i)\right)^{w_i}, 1 - \otimes_{i=1}^{5} (1-T_i)^{w_i}, \otimes_{i=1}^{5} F_i^{w_i}, \otimes_{i=1}^{5} (\Pi_i^-)^{w_i} \rangle \\ &= \langle 1 - (0.9^{0.1} 0.8^{0,2} 0, 9^{0.4} 0.9^{0.1} 0.6^{0.2}), 1 - (0.7^{0.1} 0.6^{0.2} 0.9^{0.4} 0.7^{0.1} 0.8^{0.2}), \\ &\quad 0.7^{0.1} 0.6^{0.2} 0.9^{0.4} 0.7^{0.1} 0.6^{0.2}, 0^{0.1} 0^{0.2} 0^{0.4} 0^{0.1} 0^{0.12} \rangle \\ &= \langle 0.189424,0.229159,0.727741,0 \rangle \end{aligned}$$

Definition 11. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^- \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then, Then, the weighted SvND geometric aggregation operatör denoted by $s_G^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ and defined as;

$$s_G^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) = \otimes_{i=1}^{n} \Upsilon_i^{w_i}$$

Based Definition 6, the operatör $s_G^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ is given as;

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Theorem 12. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^- \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$. Then, Then, the weighted SvND geometric aggregation operator $s_G^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ calculated as;

$$s_G^w(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) = \langle \otimes_{i=1}^{n}(1-I_i)^{w_i}, \otimes_{i=1}^{n}(T_i)^{w_i}, 1-\otimes_{i=1}^{n}(1-F_i)^{w_i}, 1-\otimes_{i=1}^{n}(1-\Pi_i^-)^{w_i} \rangle$$

Example 13. Let $\Upsilon_1 = \langle 0.1,0.4,0.6,0.2 \rangle$, $\Upsilon_2 = \langle 0.2,0.4,0.1,0.12 \rangle$, $\Upsilon_3 = \langle 0.4,0.6,0.2,0.18 \rangle$, $\Upsilon_4 = \langle 0.1,0.3,0.7,0 \rangle$, $\Upsilon_5 = \langle 0.2,0.4,0,0.4 \rangle \in$ SvND(U) and $w = (0.1,0.2,0.4,0.1,0.2)$.

Then, $s_G^w(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5)$ is found as;

$$\begin{aligned} s_G^w(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4, \Upsilon_5) &= \langle \otimes_{i=1}^{5}(1-I_i)^{w_i}, \otimes_{i=1}^{5}(T_i)^{w_i}, 1-\otimes_{i=1}^{5}(1-F_i)^{w_i}, 1-\otimes_{i=1}^{5}(1-\Pi_i^-)^{w_i} \rangle \\ &= \langle 0.730037,0.457091,0.27556,0.266934 \rangle \end{aligned}$$

Definition 14. Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^- \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ be a weighted vector such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$ and $v = (v_1, v_2, \ldots, v_n)$ be a position such that $v_j \in [0,1]$, $\sum_{j=1}^{n} v_j = 1$. Then, the weighted hybrid ordered arithmetic operator denoted by $s_{OHA}^q(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ and defined as;

$$s_{OHA}^q(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) = \sqrt[q]{\bigoplus_{k=1}^{n} w_k (B_k)^q}$$

Here and $\widehat{B_k}$ denotes the k-th largest $B_j = n.V_j.\Upsilon_j$.

Also, we have based on Definition 6 as;

Theorem 15. . Let $\Upsilon_i = \langle (1-I_i), T_i, F_i, \Pi_i^- \rangle$, $i \in I_n = \{1,2,\ldots,n\}$ be a collection SvND sets Let w_i be the weight of Υ_i and let $w = (w_1, w_2, \ldots, w_n)$ be a weighted vector such that $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$ and $v = (v_1, v_2, \ldots, v_n)$ be a position such that $v_j \in [0,1]$, $\sum_{j=1}^{n} v_j = 1$. Then, the weighted hybrid ordered arithmetic operator $s_{OHA}^q(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n)$ calculated as;

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$$
\begin{aligned}
s_{OHA}^{q}(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) &= \sqrt[q]{\oplus_{k=1}^{n} w_k (B_k)^q} \\
s_A^{w}(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) &= \oplus_{k=1}^{n} w_k B_k \\
&= \langle 1 - \otimes_{k=1}^{n} \left(1 - (1 - I_k)\right)^{w_k}, 1 - \otimes_{k=1}^{n} (1 - T_k)^{W_k}, \otimes_{k=1}^{n} F_k^{w_k}, \otimes_{k=1}^{n} (\Pi_k^-)^{w_k} \rangle \\
B_k &= \left((1 - I_k), T_k, F_k, \Pi_k^-\right) \\
(B_k)^q &= \langle (1 - I_k)^q, (T_k)^q, 1 - (1 - F_k)^q, 1 - (1 - \Pi_k^-)^q \rangle \\
s_{OHA}^{q} &= \langle 1 - \otimes_{k=1}^{n} (1 - (1 - I_k)^q)^{w_k}, 1 - \otimes_{k=1}^{n} \left(1 - T_k^q\right)^{W_k}, \otimes_{k=1}^{n} (1 - (1 - F_k)^q)^{w_k}, \\
&\quad \otimes_{k=1}^{n} (1 - (1 - (\Pi_k^-)^q)^{w_k} \rangle \\
s_{OHA}^{q}(\Upsilon_1, \Upsilon_2, \ldots, \Upsilon_n) &= \langle (1 - \otimes_{k=1}^{n} (1 - (1 - I_k)^q)^{w_k})^{1/q}, \left(1 - \otimes_{k=1}^{n} \left(1 - T_k^q\right)^{W_k}\right)^{1/q}, \\
&\quad (\otimes_{k=1}^{n} (1 - (1 - F_k)^q)^{w_k})^{1/q}, (\otimes_{k=1}^{n} (1 - (1 - (\Pi_k^-)^q)^{w_k})^{1/q} \rangle
\end{aligned}
$$

5. AN APPLICATION OF SVND SETS IN MULTI-CRITERIA DECISION-MAKING PROBLEMS

Let $O = \{o_1, o_2, \ldots, o_n\}$ be the set of criteria and $X = \{x_1, x_2, \ldots, x_m\}$ be the set of alternatives. Then, let the value of the i-th alternative with respect to the j-th criterion be denoted by $S_{ij} =< (1 - I_{ij}, T_{ij}, F_{ij}, \Pi_{ij}^- >$ $(i = 1,2,\ldots,m;\ j = 1,2,\ldots,n)$. The matrix $\left(S_{ij}\right)_{m\times n}$ is called the SvND decision matrix.

Now, in order to rank mmm alternatives according to nnn criteria, we present the following algorithm.

Algorithm:

Step 1. Construct the SvND decision matrix $\left(S_{ij}\right)_{m\times n}$

Step 2. Let the weight of that criterion be $w_j (j = 1,2,\ldots,n)$, $\sum_{j=1}^{n} w_j = 1$, and provide the weight vector $W = (w_1, w_2, \ldots, w_n)$;

Step 3. Provide the position weight vector $V = (v_1, v_2, \ldots, v_m)^T$, with its value set to $v_j (j = 1,2,\ldots,n)$, $\sum_{j=1}^{n} v_j = 1$

Step 4. Calculate the **SvND decision matrix** of size $\left(\widetilde{S_{ij}}\right)_{m\times n}$ using $\widetilde{S_{ij}} = m.w_i.S_{ij}, (i = 1,2,\ldots,m; j = 1,2,\ldots,n)$.

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Step 5. Sort the elements $\tilde{S}_{ij}(i = 1,2,\dots,m)$ in non-decreasing order according to Equations [skor1]–[skor3], and determine the k-th largest **SvND** value as için $\tilde{B}_{kj} = \langle(1 - I_{kj}, T_{kj}, F_{kj}, \Pi_{kj}^{-}\rangle$ for each **j**. Then construct the $\left(\tilde{B}_{kj}\right)_{m\times n}$ **SvND** decision matrix.

Step 6. For each alternative **i**, determine the comprehensive evaluation $s_i = S_{GH}^{q}\left(\tilde{B}_{k1}, \tilde{B}_{k1}, \dots, \tilde{B}_{kn}\right)$ using the **SvND generalized hybrid weighted average operator.**

Step 7. For each alternative **i**, find the score values of s_i for the comprehensive evaluation $s_i = S_{GH}^{q}\left(\tilde{B}_{k1}, \tilde{B}_{k1}, \dots, \tilde{B}_{kn}\right)$ according to Equations [skor1]–[skor3], and then sort them."

Numerical Example:

In this section, an application is presented on how the SvND sets can be used within the generalized hybrid weighted average method for a multi-criteria decision-making problem related to supplier selection. The goal is to determine the best supplier and the ranking order of suppliers for a company using the SvND generalized hybrid weighted average method algorithm.

A company plans to find a suitable supplier for purchasing equipment parts. The purchasing manager in the company considers four attributes (criteria/factors):

- Performance (o_1): Delivery, quality, price.
- Technology (o_2): Production capacity, design capability, ability to adapt to technological changes.
- Finance (o_3): Economic performance, financial stability.
- Organizational Culture and Strategy (o_4): Sense of trust, internal and external integration of suppliers, compatibility of functions between buyer and supplier.

These four attribute sets are denoted by $O = \{o_1, o_2, o_3, o_4\}$. After the initial evaluation, four suppliers have been identified for further assessment and selection. This set of four suppliers is denoted by $X = \{x_1, x_2, x_3, x_4\}$.

Algorithm:

Step 1. Let $O = \{o_1, o_2, o_3, o_4\}$ be the set of criteria and $X = \{x_1, x_2, x_2, x_4\}$ be the set of alternatives. The elements $S_{ij} =< (1 - I_{ij}, T_{ij}, F_{ij}, \Pi_{ij}^{-} >\ (i = 1,2,3,4;\ j = 1,2,3,3)$ of

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SvND represent the evaluation of alternative x_i with respect to criterion o_j as given by the decision maker. The $(S_{ij})_{4\times4}$ **SvND decision matrix** is presented as follows:

$$[S_i\,j]_{4x4} = \begin{array}{c} \\ o_1 \\ o_2 \\ o_3 \\ o_4 \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & x_3 & x_4 \end{array} \\ \begin{pmatrix} \langle 0.1,0.3,0.7,0\rangle & \langle 0.3,0.2,0.6,0.12\rangle & \langle 0.5,0.3,0.3,0.12\rangle & \langle 0.7,0.4,0.6,0\rangle \\ \langle 0.2,0.4,0.6,0\rangle & \langle 0.2,0.4,0.2,0.08\rangle & \langle (0.3,0.4,0.5,0.05\rangle & \langle (0.4,0.5,0.3,0.06\rangle \\ \langle 0.1,0.1,0.9,0\rangle & \langle 0.1,0.3,0.7,0\rangle & \langle (0.4,0.2,0.6,0.12\rangle & \langle 0.3,0.3,0.5,0.1\rangle \\ \langle (0.3,0.2,0.4,0.16\rangle & \langle 0.5,0.6,0.2,0.04\rangle & \langle (0.4,0.2,0.5,0.15\rangle & \langle 0.2,0.2,0.1,0.07\rangle \end{pmatrix} \end{array}$$

Step 2. Let $w_j(j = 1,2,3,4)$ be the weight of criterion o_j, and provide the weight vector **w** $W = (0.35,0.3,0.25,0.10)^T$ such that the sum equals $\sum_{j=1}^{4} w_j = 1$.

Step 3. The position weight vector $V = (v_1, v_2, \ldots, v_m)^T$ associated with $S_{w,v}^{GH}$ is given as

$$v = (0.24,0.26,0.26,0.24)^T$$

Step 4. The **SvND sets** are calculated using $\widetilde{S_{ij}} = m.w_i.S_{ij}, (i = 1,2,\ldots,m; j = 1,2,\ldots,n)$ for

$$\begin{aligned} \tilde{S}_{O11} &= 4 \times 0.35 \times \tilde{S}_{11} \\ &= 4 \times 0.35 \times \langle 0.1,0.3,0.7,0\rangle \\ &= \langle (1-(1-0.1)^{4\times0.35}, (1-(1-0.3)^{4\times0.35}, 0.7^{4\times0.35}, 0^{4\times0.35}\rangle \\ &= \langle 1-0.9^{1.4}, 1-0.7^{1.4}, 0.7^{1.4}, 0^{1.4}\rangle \\ &= \langle 0.1372,0.3930,0.6069,0\rangle \end{aligned}$$

Similarly, the other **SvND sets** are also obtained.

The $\tilde{S}_{oij} = m.w_i.S_{o_{ij}}(i = 1,2,3,4; j = 1,2,3,4)$and **SvND decision matrix** are given as follows with $\tilde{S}_o = \left(S_{o_{ij}}\right)_{4\times4}$:

$$\left(S_{O_{ik}}\right)_{4\times4} = \begin{pmatrix} \langle 0.1372,0.3930,0.6069,0\rangle & \langle 0.3930,0.2683,0.4891,0.0513\rangle \\ \langle 0.2349,0.4582,0.5417,0\rangle & \langle 0.2349,0.4582,0.1449,0.482\rangle \\ \langle 0.1,0.1,0.9,0\rangle & \langle 0.1,0.3,0.7,0\rangle \\ \langle 0.1329,0.0853,0.6931,0.4804\rangle & \langle 0.2421,0.3068,0.5253,0.2759\rangle \end{pmatrix}$$

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$$\begin{matrix} \langle 0.6210,0.3930,0.1853,0.0513\rangle & \langle 0.8146,0.5108,0.4891,0\rangle \\ \langle 0.3481,0.4582,0.4352,0.0274\rangle & \langle 0.4582,0.5647,0.2358,0.0341\rangle \\ \langle 0.4,0.2,0.6,0.12\rangle & \langle 0.3,0.3,0.5,0.1\rangle \\ \langle 0.1848,0.0853,0.7578,0.4682\rangle & \langle 0.0853,0.0853,0.3981,0.3451\rangle \end{matrix}\Bigg)$$

Step 5. The scores of the alternatives (suppliers) $\widetilde{S_{o_{ij}}}$ on the four attributes $(o_i, i = 1,2,3,4)$ of the intuitive fuzzy sets are calculated as follows:

$$M\left(\tilde{S}_{o_{ij}}\right) = \frac{1+\left[\left(1-I_{ij}\right)T_{ij}F_{ij}\Pi_{ij}^{-}\right]}{2}$$

$$\begin{aligned} M\left(\tilde{S}_{o_{11}}\right) &= 0{,}0211 \\ M\left(\tilde{S}_{o_{21}}\right) &= 0{,}0493 \\ M\left(\tilde{S}_{o_{31}}\right) &= 0{,}009 \\ M\left(\tilde{S}_{o_{41}}\right) &= -0{,}0410 \\ M\left(\tilde{S}_{o_{12}}\right) &= 0{,}0391 \\ M\left(\tilde{S}_{o_{22}}\right) &= 0{,}0744 \\ M\left(\tilde{S}_{o_{32}}\right) &= 0{,}009 \\ M\left(\tilde{S}_{o_{42}}\right) &= -0{,}0079 \\ M\left(\tilde{S}_{o_{13}}\right) &= 0{,}1656 \\ M\left(\tilde{S}_{o_{23}}\right) &= 0{,}0792 \\ M\left(\tilde{S}_{o_{33}}\right) &= 0 \\ M\left(\tilde{S}_{o_{43}}\right) &= -0{,}0623 \\ M\left(\tilde{S}_{o_{14}}\right) &= 0{,}2125 \\ M\left(\tilde{S}_{o_{24}}\right) &= 0{,}1531 \\ M\left(\tilde{S}_{o_{34}}\right) &= 0{,}021 \\ M\left(\tilde{S}_{o_{44}}\right) &= -0{,}0098 \end{aligned}$$

Accordingly, the **SvND sets** are ranked based on the above scoring function method:

$$\begin{matrix} \tilde{S}_{o_{14}} > & \tilde{S}_{o_{13}} > & \tilde{S}_{o_{12}} > & \tilde{S}_{o_{11}} \\ \tilde{S}_{o_{24}} > & \tilde{S}_{o_{23}} > & \tilde{S}_{o_{22}} > & \tilde{S}_{o_{21}} \\ \tilde{S}_{o_{34}} > & \tilde{S}_{o_{31}} > & \tilde{S}_{o_{32}} > & \tilde{S}_{o_{33}} \\ \tilde{S}_{o_{42}} > & \tilde{S}_{o_{44}} > & \tilde{S}_{o_{41}} > & \tilde{S}_{o_{43}} \end{matrix}$$

As a result:

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$$\tilde{B}_{11}=\tilde{S}_{o_{14}},\quad \tilde{B}_{12}=\tilde{S}_{o_{13}},\quad \tilde{B}_{13}=\tilde{S}_{o_{12}},\quad \tilde{B}_{14}=\tilde{S}_{o_{11}}$$
$$\tilde{B}_{21}=\tilde{S}_{o_{24}},\quad \tilde{B}_{22}=\tilde{S}_{o_{23}},\quad \tilde{B}_{23}=\tilde{S}_{o_{22}},\quad \tilde{B}_{24}=\tilde{S}_{o_{21}}$$
$$\tilde{B}_{31}=\tilde{S}_{o_{34}},\quad \tilde{B}_{32}=\tilde{S}_{o_{31}},\quad \tilde{B}_{33}=\tilde{S}_{o_{32}},\quad \tilde{B}_{34}=\tilde{S}_{o_{33}}$$
$$\tilde{B}_{41}=\tilde{S}_{o_{42}},\quad \tilde{B}_{42}=\tilde{S}_{o_{44}},\quad \tilde{B}_{43}=\tilde{S}_{o_{41}},\quad \tilde{B}_{44}=\tilde{S}_{o_{43}}$$

$$\left(B_{kj}\right)_{4\times4}=\begin{pmatrix} \langle 0.8146,0.5108,0.4891,0\rangle & \langle 0.621,0.393,0.1853,0.0513 \\ \langle 0.4582,0.5647,0.2358,0.0341\rangle & \langle 0.3481,0.4582,0.4352,0.0274\rangle \\ \langle 0.3,0.3,0.5,0.1\rangle & \langle 0.1,0.1,0.9,0\rangle \\ \langle 0.2421,0.3068,0.5253,0.2759\rangle & \langle 0.0853,0.0853,0.3981,0.3451\rangle \end{pmatrix}$$

$$\begin{pmatrix} \langle 0.393,0.2683,0.4891,0.0513\rangle & \langle 0.1372,0.393,0.6069,0\rangle \\ \langle 0.2349,0.4582,0.1449,0.0482\rangle & \langle 0.2349,0.4582,0.5417,0\rangle \\ \langle 0.1,0.3,0.7,0\rangle & \langle 0.4,0.2,0.6,0.12\rangle \\ \langle 0.132,0.0853,0.6931,0.4804\rangle & \langle 0.1848,0.0853,0.7578,0.4682\rangle \end{pmatrix}$$

The matrix was constructed.

Step 6. For each alternative (supplier) $x_j \in X(j=1,2,\ldots,n)$, the comprehensive evaluation is calculated using the **SvND generalized hybrid weighted average operator** $S_{W,V}^{GH}$, that is:

$$\begin{aligned} S_{W,V}^{GH}(A_j) &= S_{W,V}^{GH}(S_{j1},S_{j2},\ldots,S_{jm}) \\ &= \langle \sqrt[q]{1-\otimes_{k=1}^{m}\left[1-\left(1-I_{jk}\right)^q\right]^{v_k}}, \sqrt[q]{(1-\otimes_{k=1}^{m}\left[1-T_{jk}^q\right]^{v_k}}, \\ &1-\sqrt[q]{1-\otimes_{k=1}^{m}\left[1-\left(1-F_{jk}\right)^q\right]^{v_k}}, 1-\sqrt[q]{1-\otimes_{k=1}^{m}\left[1-\left(1-\pi_{jk}^{-}\right)^q\right]^{v_k}}\rangle \end{aligned}$$

Using the equation, the comprehensive evaluations of the alternatives (suppliers) $x_j(j=1,2,3,4)$ are obtained as follows:

When **q = 2**, the equations can be easily derived as follows:

$$\begin{aligned} S_{W,V}^{GH}(A_1) &= S_{W,V}^{GH}(S_{11},S_{12},S_{13},S_{14}) \\ &= \langle \sqrt{1-(1-0.8146^2)^{0.24}(1-0.621^2)^{0.26}(1-0.393^2)^{0.26}(1-0.1372^2)^{0.24}}, \\ &\sqrt{1-(1-0.5108^2)^{0.24}(1-0.3939^2)^{0.26}(1-0.2683^2)^{0.26}(1-0.393^2)^{0.24}}, \\ &1-\sqrt{1-[1-(1-0.4891)^2]^{0,24}[1-(1-0.1853)^2]^{0,26}[1-(1-0.4891)^2]^{0,26}[1-(1-0.6069)^2]^{0,24}}, \\ &1-\sqrt{1-[1-(1-0)^2]^{0,24}[1-(1-0.0513)^2]^{0,26}[1-(1-0.0513)^2]^{0,26}[1-(1-0)^2]^{0,24}}\rangle \\ &= \langle 0.17679,0.08064,0.31098,0\rangle \end{aligned}$$

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$$
\begin{aligned}
S_{W,V}^{GH}(A_2) &= S_{W,V}^{GH}(S_{21}, S_{22}, S_{23}, S_{24}) \\
&= \langle \sqrt{1-(1-0.4582^2)^{0.24}(1-0.3481^2)^{0.26}(1-0.2349^2)^{0.26}(1-0.2349^2)^{0.24}}, \\
&\sqrt{1-(1-0.5647^2)^{0.24}(1-0.4582^2)^{0.26}(1-0.4582^2)^{0.26}(1-0.4582^2)^{0.24}}, \\
&1-\sqrt{1-[1-(1-0.2358)^2]^{0,24}[1-(1-0.4352)^2]^{0,26}[1-(1-0.1449)^2]^{0,26}[1-(1-0.5417)^2]^{0,24}}, \\
&1-\sqrt{1-[1-(1-0.0341)^2]^{0,24}[1-(1-0.0274)^2]^{0,26}[1-(1-0.0482)^2]^{0,26}[1-(1-0)^2]^{0,24}}\rangle \\
&= \langle 0.05588, 0.11879, 0.24618, 0 \rangle
\end{aligned}
$$

$$
\begin{aligned}
S_{W,V}^{GH}(A_3) &= S_{W,V}^{GH}(S_{31}, S_{32}, S_{33}, S_{34}) \\
&= \langle \sqrt{1-(1-0.3^2)^{0.24}(1-0.1^2)^{0.26}(1-0.1^2)^{0.26}(1-0.4^2)^{0.24}}, \\
&\sqrt{1-(1-0.3^2)^{0.24}(1-0.1^2)^{0.26}(1-0.3^2)^{0.26}(1-0.2^2)^{0.24}}, \\
&1-\sqrt{1-[1-(1-0.5)^2]^{0,24}[1-(1-0.9)^2]^{0,26}[1-(1-0.7)^2]^{0,26}[1-(1-0.6)^2]^{0,24}}, \\
&1-\sqrt{1-[1-(1-0.1)^2]^{0,24}[1-(1-0)^2]^{0,26}[1-(1-0)^2]^{0,26}[1-(1-0.12)^2]^{0,24}}\rangle \\
&= \langle 0.03367, 0.02891, 0.43554, 0 \rangle
\end{aligned}
$$

And

$$
\begin{aligned}
S_{W,V}^{GH}(A_4) &= S_{W,V}^{GH}(S_{14}, S_{24}, S_{34}, S_{44}) \\
&= \langle \sqrt{1-(1-0.2421^2)^{0.24}(1-0.0853^2)^{0.26}(1-0.132^2)^{0.26}(1-0.1848^2)^{0.24}}, \\
&\sqrt{1-(1-0.3068^2)^{0.24}(1-0.0853^2)^{0.26}(1-0.0853^2)^{0.26}(1-0.0853^2)^{0.24}}, \\
&1-\sqrt{1-[1-(1-0.5253)^2]^{0,24}[1-(1-0.3981)^2]^{0,26}[1-(1-0.6931)^2]^{0,26}[1-(1-0.7578)^2]^{0,24}}, \\
&1-\sqrt{1-[1-(1-0.2759)^2]^{0,24}[1-(1-0.3451)^2]^{0,26}[1-(1-0.4804)^2]^{0,26}[1-(1-0.4682)^2]^{0,24}}\rangle \\
&= \langle 0.01444, 0.01443, 0.40187, 0.30767 \rangle
\end{aligned}
$$

The $S_{W,V}^{GH}(A_j)$ $(j = 1,2,3,4)$ scores are calculated using the $M_3(S_{ij}) = \frac{1+[(1-I).T-(1-I).F.\pi^-]}{2}$ **scoring function** as follows:

$$
\begin{aligned}
M\left(S_{W,V}^{GH}(A_1)\right) &= 0.50106 \\
M\left(S_{W,V}^{GH}(A_2)\right) &= 0.50058 \\
M\left(S_{W,V}^{GH}(A_3)\right) &= 0.5001 \\
M\left(S_{W,V}^{GH}(A_4)\right) &= 0.4991
\end{aligned}
$$

It is clearly observed that $M\left(S_{W,V}^{GH}(A_1)\right) > M\left(S_{W,V}^{GH}(A_2)\right) > M\left(S_{W,V}^{GH}(A_3)\right) > M\left(S_{W,V}^{GH}(A_4)\right)$

Therefore, using the **SvND set ranking method,** the ranking of the suppliers is as follows:

$$x_1 > x_2 > x_3 > x_4$$

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The best supplier is identified as x_1. From the calculation results, the ranking of the suppliers for **j = 1, 2, 3, 4** is completely the same, and when the parameter **q = 1 , q = 2** or $q \to +\infty$ the ranking is $x_1 > x_2 > x_3 > x_4$.

Moreover, in these cases, the best supplier is the same, that is, x_4. However, when $q \to 0$, the ranking of the suppliers is different. In this case, the ranking is $x_2 > x_1 > x_3 > x_4$.

In general, different values of the parameter **q** can affect the ranking of the suppliers. Therefore, the specific and appropriate value of q should be selected according to the attributes and requirements in real management situations.

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GEARBOX FAULT DİAGNOSİS USİNG MULTİ-SENSOR VİBRATİON ANALYSİS AND LİGHT GRADİENT BOOSTİNG MACHİNE

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Abstract

Gearbox fault diagnosis plays a crucial role in ensuring the reliability and safety of industrial rotating machinery. Early detection of faults, such as broken gear teeth, can significantly reduce maintenance costs and prevent unexpected system failures. In this study, a data-driven gearbox fault diagnosis framework based on multi-sensor vibration analysis and the Light Gradient Boosting Machine (LGBM) algorithm is proposed. Vibration signals were collected from four sensors mounted in different directions under varying load conditions for healthy and broken tooth gearbox states. Time-domain and frequency-domain statistical features were extracted to characterize the dynamic behavior of the gearbox. The extracted features were then used to train and test the LGBM classifier. The performance of the proposed method was evaluated using classification accuracy as the primary metric. Experimental results demonstrate that the proposed approach achieves a high classification accuracy of 98%, indicating its strong capability in distinguishing between healthy and faulty gearbox conditions. The findings confirm that the combination of multi-sensor vibration features and LGBM provides an effective and efficient solution for gearbox condition monitoring and fault diagnosis in industrial applications.

Keywords: Gearbox fault diagnosis, vibration analysis, machine learning, LightGBM, condition monitoring

1. Introduction

Gearboxes are critical components in many industrial systems, including manufacturing lines, power transmission systems, and rotating machinery. Their reliable operation is essential for ensuring productivity, safety, and cost efficiency. However, gearboxes are frequently subjected to harsh operating conditions such as variable loads, high rotational speeds, and long-term mechanical stress, which can lead to different types of faults. Among these, broken tooth faults

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are particularly severe, as they can cause abnormal vibrations, accelerated wear, and even catastrophic system failure if not detected at an early stage.

With the rapid development of machine learning techniques, data-driven fault diagnosis methods have gained increasing attention. Xu et al. reviewed wind turbine gearbox fault diagnosis, emphasizing that accuracy depends on the synergy between feature extraction and ML. They argue that data quality and preprocessing are as vital as algorithm tuning, providing a roadmap for integrating robust features with ML to simplify complex fault detection [1]. Afia et al. proposed an intelligent diagnostic framework for gearboxes using Robust Empirical Mode Decomposition (REMD) to decompose vibration signals into Intrinsic Mode Functions (IMFs). They utilized the Equilibrium Optimizer (EO) for feature selection, which reduced dimensionality and prevented overfitting before classifying faults with Random Forest and KNN [2]. Fu et al. reviewed gear transmission fault diagnosis, summarizing time, frequency, and time-frequency domain analyses. The study tracks the evolution from shallow to deep learning and highlights future directions: weak signal extraction, composite fault identification, and the integration of multi-source data fusion for enhanced safety [3]. Patil and Wani proposed using YAMNet, a pre-trained audio network, for gear fault detection via transfer learning. By converting acoustic noise data into Mel Spectrograms, they leveraged YAMNet's sound event detection capabilities. The model, fine-tuned on healthy and faulty gear data, achieved 95% accuracy in identifying tooth failures [4]. Kumar et al. introduced LHOM (Logarithmic Higher Order Moments) as a novel feature for gearbox fault diagnosis. Beyond the 5th order, LHOM scales linearly with fault severity. Using ML classifiers, they proved it reliably identifies localized faults across three benchmark datasets, outperforming traditional metrics [5]. Chen et al. proposed a physics-informed hyperparameter selection strategy for LSTM networks. Instead of minimizing validation error, they optimized hyperparameters to maximize the discrepancy between healthy and simulated faulty states. This approach significantly improved the detection of gear tooth cracks and wear [6]. Among various machine learning methods, tree-based ensemble algorithms have demonstrated strong performance in classification tasks due to their ability to handle nonlinear relationships and complex feature interactions. The Light Gradient Boosting Machine (LGBM) is a recent and efficient gradient boosting framework that offers high accuracy, fast training speed, and low memory consumption. Its leaf-wise tree growth strategy enables effective learning from high-dimensional feature spaces, making it well suited for vibration-based fault diagnosis problems.

In this study, a gearbox fault diagnosis framework based on multi-sensor vibration data and the LGBM algorithm is proposed. Time-domain and frequency-domain features are extracted from vibration signals collected under different load conditions for healthy and broken tooth gearbox states. The performance of the proposed approach is evaluated using classification accuracy as the primary metric. The experimental results demonstrate that the proposed method can accurately distinguish between healthy and faulty gearbox conditions, highlighting its potential for practical industrial condition monitoring applications.

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2. MATERIALS AND METHODS

2.1. Dataset Description

In this study, the Gearbox Fault Diagnosis Dataset was used to evaluate the performance of a machine learning–based fault classification approach [7]. There are limited publicly available datasets in the field of mechanical engineering that are specifically designed for applying machine learning techniques in industrial environments. Therefore, this dataset provides a valuable resource for gearbox fault diagnosis research. The dataset was obtained using SpectraQuest's Gearbox Fault Diagnostics Simulator, where vibration signals were recorded under controlled experimental conditions. Four vibration sensors were mounted on the gearbox in four different directions to capture vibration responses comprehensively. Measurements were conducted under varying load conditions ranging from 0% to 90%, with increments of 10%. Two different operational conditions were considered:

- Healthy gearbox condition
- Broken tooth fault condition

The dataset consists of 20 data files in total. Ten files correspond to the healthy gearbox condition, while the remaining ten files represent the broken tooth fault condition. Each file is associated with a specific load level. The main characteristics of the dataset are summarized in Table 1.

Table 1. Main characteristics of the gearbox fault diagnosis dataset [7]

Feature	**Description**
Dataset name	Gearbox Fault Diagnosis Dataset
Measurement system	SpectraQuest Gearbox Fault Diagnostics Simulator
Number of sensors	4 vibration sensors
Sensor placement	Four different directions
Operating conditions	Healthy, Broken Tooth
Total number of files	20
Healthy condition files	10
Faulty condition files	10
Load range	0% – 90%
Load increment	10%
Data type	Vibration signals
Application	Gearbox fault diagnosis

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2.2. Data Preprocessing

Before applying the machine learning algorithm, the vibration data were preprocessed to ensure suitability for classification. Each data file was labeled according to its operating condition, where the healthy condition was assigned label 0, and the broken tooth condition was assigned label 1. Feature extraction techniques were applied to transform raw vibration signals into representative feature vectors. Additionally, normalization was performed to reduce the influence of scale differences among features and to improve model convergence.

2.3. Light Gradient Boosting Machine

The LGBM algorithm was employed as the classification model in this study. LGBM is a tree-based gradient boosting method known for its high computational efficiency and low memory consumption, making it suitable for handling complex and high-dimensional data [8]. Unlike traditional level-wise tree growth strategies, LGBM adopts a leaf-wise growth approach, where the leaf with the maximum loss reduction is expanded. This strategy enables the model to capture nonlinear relationships more effectively and often results in improved classification performance. Given the nonlinear and complex nature of gearbox vibration signals, LGBM was selected as an appropriate algorithm for distinguishing between healthy and faulty gearbox conditions.

2.4. Model Training and Performance Evaluation

The dataset was divided into training and testing subsets. The LGBM model was trained using the training data and evaluated on the testing data [9]. The performance of the proposed model was assessed using Accuracy as the sole evaluation metric [10]. Accuracy represents the proportion of correctly classified samples relative to the total number of samples and is defined as:

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (1)$$

where TP denotes true positives, TN true negatives, FP false positives, and FN false negatives. Accuracy was chosen as the evaluation metric due to the balanced nature of the dataset and its effectiveness in reflecting the overall classification performance of the model.

3. Results And Discussion

Figure 1 illustrates a comparative analysis of the vibration responses in the time domain for healthy and faulty gearbox states. In Figure 1(a), corresponding to the healthy condition, the vibration signal exhibits relatively consistent amplitude variations with fewer extreme peaks, indicating stable dynamic behavior of the gearbox. In contrast, Figure 1(b), representing the broken tooth condition, shows more irregular fluctuations and pronounced amplitude variations. These characteristics reflect the impact of the broken tooth fault on the dynamic response of the gearbox, leading to increased vibration instability. The observable differences between the two signals demonstrate that time-domain vibration characteristics contain

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discriminative information suitable for fault detection and classification using machine learning approaches.

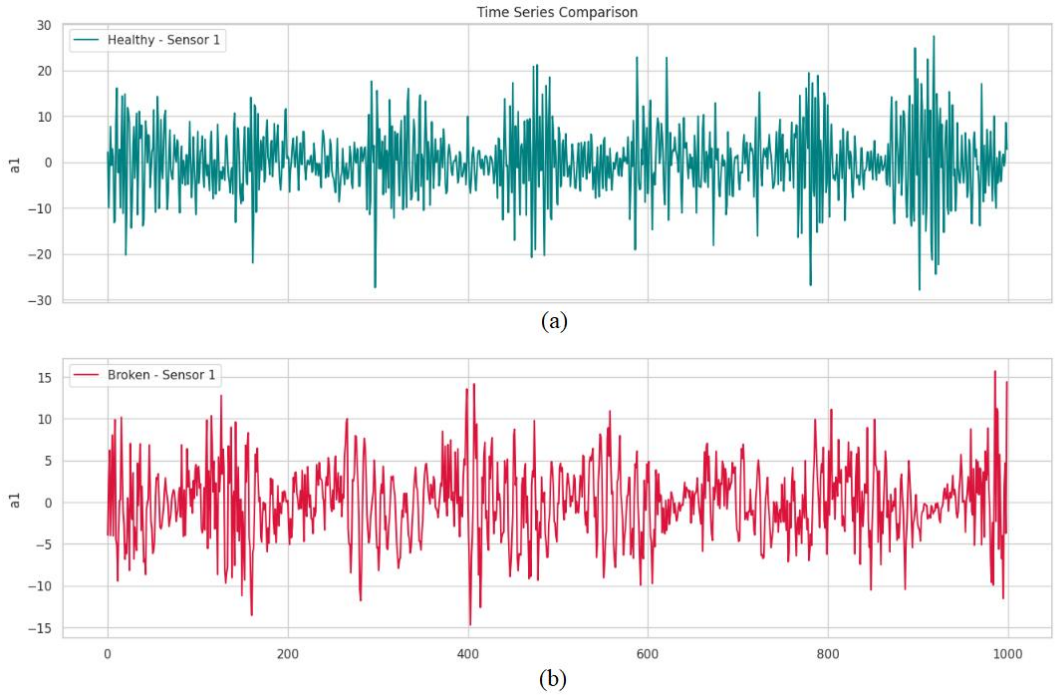

Figure 1. Time-domain vibration signals acquired from Sensor 1 under two different gearbox operating conditions: **(a)** healthy condition and **(b)** broken tooth fault condition.

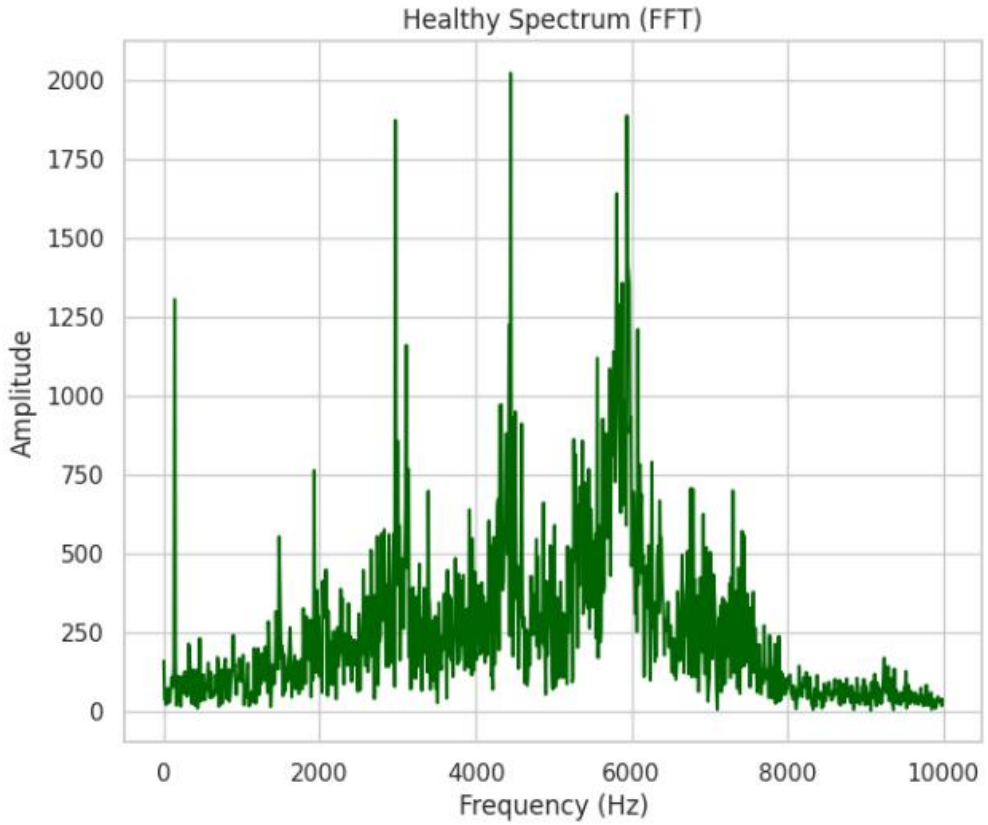

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Figure 2. Frequency-domain representation (FFT spectrum) of the vibration signal obtained from Sensor 1 under the healthy gearbox condition.

Figure 2 presents the frequency spectrum of the vibration signal for the healthy gearbox condition obtained through Fast Fourier Transform (FFT) analysis. The spectrum is characterized by distinct dominant frequency components with relatively stable and well-defined peaks, which are associated with normal gear meshing frequencies and their harmonics. The absence of excessive broadband energy and irregular high-amplitude components indicates a stable mechanical operation without significant fault-induced excitations. This frequency-domain behavior reflects the normal dynamic response of the gearbox and serves as a reference for comparison with faulty conditions, where additional frequency components and elevated amplitudes are typically expected. The results demonstrate that FFT-based features provide meaningful information for distinguishing healthy operating states in gearbox fault diagnosis.

Figure 3 illustrates the FFT spectrum of the vibration signal corresponding to the faulty gearbox with a broken tooth. Compared to the healthy spectrum, the faulty condition exhibits increased spectral complexity characterized by higher amplitude peaks, additional frequency components, and elevated broadband energy across a wider frequency range. These pronounced peaks and irregular distributions are indicative of fault-induced impulsive excitations and abnormal gear meshing behavior caused by the broken tooth. The presence of such frequency-domain anomalies highlights the sensitivity of FFT-based analysis to gearbox faults and demonstrates its effectiveness in capturing discriminative features for fault diagnosis and subsequent classification using machine learning models.

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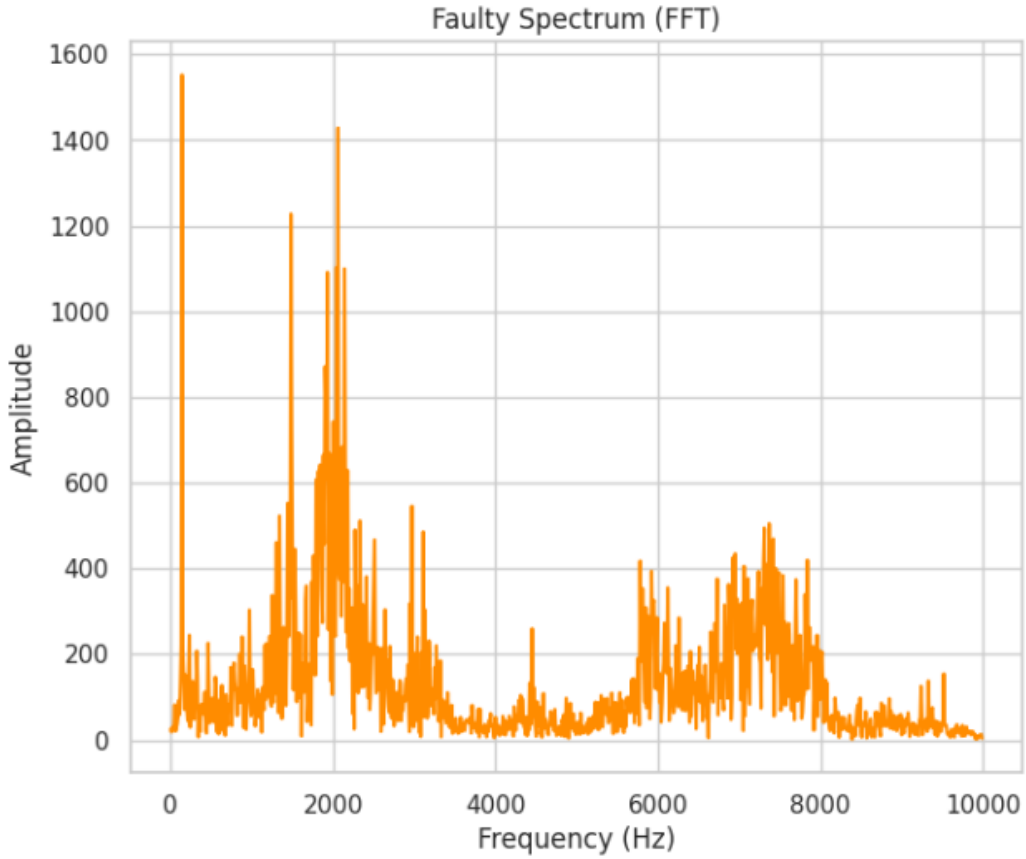

Figure 3. Frequency-domain representation (FFT spectrum) of the vibration signal obtained from Sensor 1 under the broken tooth fault condition.

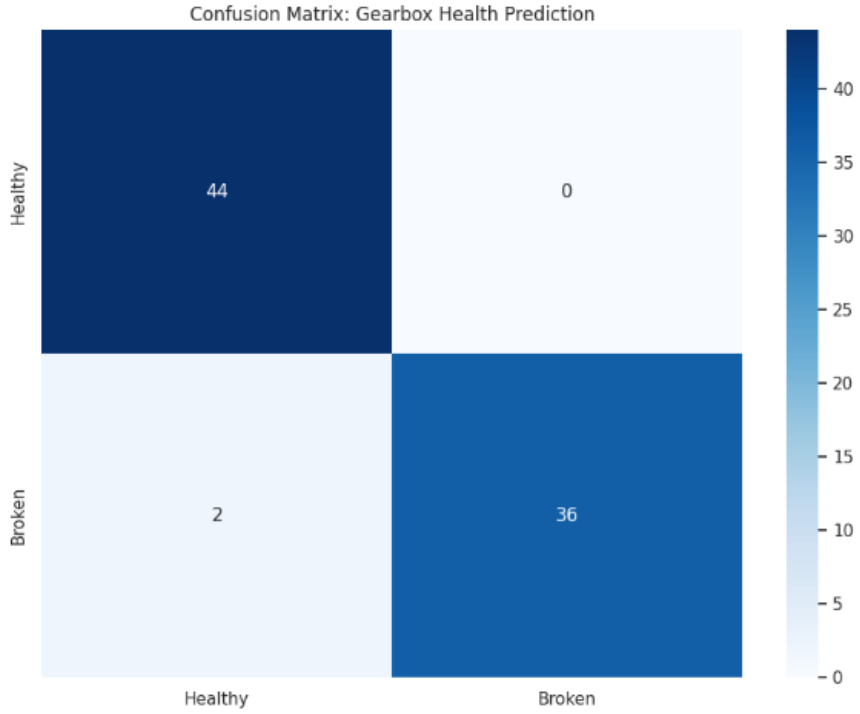

Figure 4. Confusion matrix of the LGBM model for gearbox health condition classification.

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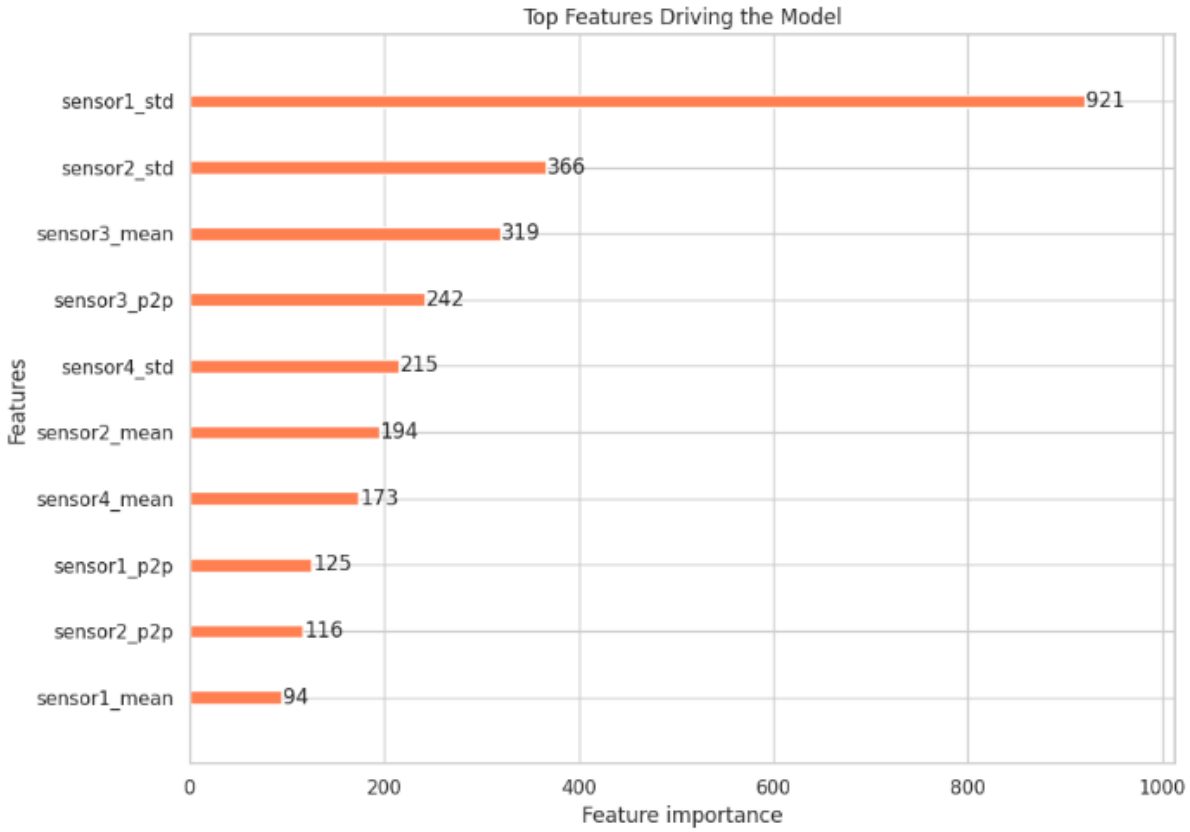

Figure 5. Feature importance ranking of the most influential statistical features used by the LGBM model for gearbox fault classification.

Figure 4 presents the confusion matrix summarizing the classification performance of the proposed LGBM-based model in distinguishing between healthy and broken tooth gearbox conditions. The model correctly classified 44 healthy samples and 36 faulty samples, while 2 faulty samples were misclassified as healthy. No healthy samples were incorrectly classified as faulty. These results indicate a high classification capability, with the majority of instances accurately identified. The low number of misclassifications demonstrates the effectiveness of the extracted vibration features and the suitability of the LGBM algorithm for gearbox fault diagnosis. Overall, the confusion matrix confirms that the proposed approach achieves strong predictive performance and reliable fault discrimination.

Figure 5 illustrates the relative importance of the top statistical features contributing to the decision-making process of the Light Gradient Boosting Machine (LGBM) model. The results indicate that the standard deviation of Sensor 1 (sensor1_std) is the most dominant feature, suggesting that vibration variability captured by this sensor plays a critical role in distinguishing healthy and faulty gearbox conditions. This is followed by sensor2_std and sensor3_mean, highlighting the significance of both signal dispersion and average amplitude characteristics across different sensor locations. Peak-to-peak (p2p) features and mean values from multiple sensors also contribute to the classification process, albeit with comparatively lower importance. The distribution of feature importance demonstrates that no single sensor

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exclusively determines the model output; instead, the model benefits from a combination of statistical features extracted from multiple sensors. These findings confirm that multi-sensor vibration analysis enhances fault sensitivity and supports the effectiveness of the proposed feature extraction strategy for gearbox fault diagnosis.

Table 2 summarizes the classification performance of the proposed Light Gradient Boosting Machine (LGBM) model in distinguishing between healthy and broken tooth gearbox conditions. The model achieves an overall accuracy of 98%, indicating excellent predictive capability. For the healthy class, a recall value of 1.00 demonstrates that all healthy samples were correctly identified, with no false negatives. The broken tooth class achieves a precision of 1.00, indicating that all samples predicted as faulty truly belonged to the faulty class, while a recall of 0.95 suggests a small number of faulty samples were misclassified as healthy. The high F1-scores for both classes (0.98 for healthy and 0.97 for broken) reflect a strong balance between precision and recall. Furthermore, the close agreement between macro and weighted averages confirms that the model performance is consistent across classes and is not biased toward a particular condition. Overall, these results demonstrate that the proposed LGBM-based approach provides reliable and robust gearbox fault classification performance.

Table 2. Classification performance metrics

Sınıf	**Precision**	**Recall**	**F1-Score**	**Support**
Healthy	0.96	1.00	0.98	44
Broken	1.00	0.95	0.97	38
Accuracy	—	—	**0.98**	**82**
Macro Avg	0.98	0.97	0.98	82
Weighted Avg	0.98	0.98	0.98	82

4. Conclusion

In this study, an intelligent gearbox fault diagnosis approach based on vibration signal analysis and the LGBM algorithm was presented. Time-domain and frequency-domain features were extracted from multi-sensor vibration data acquired under different load conditions for healthy and broken tooth gearbox states. The extracted statistical features effectively captured the dynamic characteristics of the gearbox system and provided discriminative information for fault classification. The proposed LGBM-based model demonstrated excellent classification performance, achieving an overall accuracy of 98%. The confusion matrix and performance metrics showed that healthy gearbox conditions were identified without misclassification, while only a small number of faulty samples were incorrectly classified. The high precision, recall, and F1-score values for both classes confirm the robustness and reliability of the proposed method. Additionally, feature importance analysis revealed that vibration variability-related features, particularly standard deviation metrics from multiple sensors, played a dominant role

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in fault discrimination, highlighting the importance of multi-sensor data fusion. The results indicate that the combination of vibration-based feature extraction and LGBM provides an effective and computationally efficient solution for gearbox fault diagnosis. The proposed approach has strong potential for practical implementation in industrial condition monitoring systems. Future work may focus on extending the method to multiple fault types, incorporating advanced signal processing techniques, and evaluating the model performance under real-time and noisy industrial operating conditions.

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REMAİNİNG USEFUL LİFE PREDİCTİON OF GEARBOX SYSTEMS USİNG A STACKİNG ENSEMBLE REGRESSİON FRAMEWORK

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Abstract

Accurate prediction of the remaining useful life (RUL) of gearbox systems is a critical task in prognostics and health management, as it enables condition-based maintenance, reduces unplanned downtime, and enhances operational reliability. Traditional data-driven RUL prediction approaches often rely on single regression models, which may struggle to capture complex degradation dynamics under noisy and nonlinear operating conditions. To address this limitation, this study proposes a stacking ensemble regression framework for gearbox RUL prediction based on vibration signal analysis. In the proposed approach, statistical, lag-based, and smoothed features are extracted from multi-sensor vibration data to characterize both instantaneous and temporal degradation behavior. Two heterogeneous base learners, namely Extra Trees Regressor and XGBoost Regressor, are employed to model complementary aspects of the degradation process. Their outputs are subsequently combined using a Ridge Regression meta-learner to generate the final RUL prediction. Experimental results demonstrate that the proposed stacking ensemble model achieves high prediction accuracy, with an MAE of 7.7997, an RMSE of 11.5621, and an R^2score of 0.8750. The findings confirm that the proposed framework effectively captures gearbox degradation trends and provides reliable RUL estimates, making it suitable for practical industrial prognostics applications.

Keywords: Remaining useful life prediction, Gearbox prognostics, Stacking ensemble learning, Vibration-based condition monitoring, Machine learning

1. Introduction

Gearbox systems are widely used in a variety of industrial applications, including wind energy systems, manufacturing equipment, and transportation machinery. Due to their continuous operation under variable load and speed conditions, gearboxes are susceptible to progressive degradation and faults such as tooth wear, surface pitting, and structural damage. Accurate estimation of the remaining useful life (RUL) of gearbox components is therefore essential for

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effective condition-based maintenance and prognostics and health management (PHM) systems.

Vibration-based condition monitoring has become one of the most effective techniques for assessing the health state of rotating machinery. Vibration signals contain rich information related to mechanical degradation and fault evolution; however, extracting meaningful degradation indicators from these signals remains a challenging task. In recent years, data-driven approaches based on machine learning have gained increasing attention for RUL prediction, as they can model complex relationships between sensor features and degradation behavior without requiring explicit physical models. Liu et al. addressed the challenge of domain shift in planetary gearboxes operating under varying conditions. They combined an LSTM-DNN architecture with domain adaptation to align data distributions between different working environments. This transfer learning approach significantly improved RUL prediction accuracy by reducing statistical discrepancies across datasets [1]. He et al. proposed a Self-Calibration Temporal Convolutional Network (SCTCN) for bearing RUL prediction. While standard TCNs use dilated causal convolutions to capture long-term history, they often lose critical local information. SCTCN adds a self-calibration module to recover these local details, resulting in more complete feature extraction and higher accuracy on both test bench and real-world wind turbine data [2]. Han et al. proposed Modulation Signal Bispectrum (MSB) to reveal the hidden modulation mechanisms in gear vibration signals. MSB outperforms traditional metrics like RMS and Kurtosis by effectively canceling noise and capturing weak degradation signatures. These optimal MSB features are then processed by an Improved Relevance Vector Machine (IMRVM) to achieve highly accurate RUL predictions [3]. Berghout and Benbouzid provided a roadmap for PHM, shifting from physical laws to ML for complex systems. They detailed the RUL pipeline—from data acquisition to evaluation—and offered guidelines to select the right ML tools based on data types, addressing future challenges in the field [4]. Liu et al. reviewed the challenges of planetary gearbox fault diagnosis, such as complex vibration modulation and non-stationary signals. They detailed six core deep learning architectures—AE, DBM, CNN, Transformer, GAN, and GNN—and their applications. To support future research, the paper also introduces a new dataset specifically for planetary gearbox health state recognition [5]. Chen et al. address the lack of faulty-state data by using LSTMs to model baseline healthy behavior. They argue that standard hyperparameter tuning (minimizing VAMSE) often fails to distinguish faults. Their solution is a physics-informed strategy that selects hyperparameters by maximizing the discrepancy between healthy data and simulated physics-informed faulty states, significantly improving the detection of gear cracks and wear [6].

Motivated by these considerations, this study proposes a stacking ensemble regression framework for gearbox RUL prediction using vibration-based features. The framework integrates Extra Trees and XGBoost regressors as base learners to capture both global degradation trends and complex nonlinear interactions, while Ridge Regression is employed as a meta-learner to combine base model outputs in a regularized manner. The proposed approach is evaluated through comprehensive experiments, including error analysis, residual distribution assessment, feature importance investigation, and continuous health monitoring scenarios. The

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results demonstrate that the stacking ensemble framework provides accurate, stable, and interpretable RUL predictions, highlighting its potential for real-world industrial prognostics applications.

2. MATERIALS AND METHODS

2.1. Dataset Description

In this study, the Gearbox Fault Diagnosis Dataset was used to evaluate the performance of a machine learning–based fault classification approach [7]. There are limited publicly available datasets in the field of mechanical engineering that are specifically designed for applying machine learning techniques in industrial environments. Therefore, this dataset provides a valuable resource for gearbox fault diagnosis research. The dataset was obtained using SpectraQuest's Gearbox Fault Diagnostics Simulator, where vibration signals were recorded under controlled experimental conditions. Four vibration sensors were mounted on the gearbox in four different directions to capture vibration responses comprehensively. Measurements were conducted under varying load conditions ranging from 0% to 90%, with increments of 10%. Two different operational conditions were considered:

- Healthy gearbox condition
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Load range	0% – 90%
Load increment	10%

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Data type	Vibration signals
Application	Gearbox fault diagnosis

2.2. Stacking Ensemble Regressor for Remaining Useful Life Prediction

In this study, the remaining useful life (RUL) of the gearbox system is predicted using a stacking ensemble regression approach based on statistical, lag-based, and smoothed features extracted from vibration signals. RUL prediction is formulated as a supervised regression problem, where the objective is to estimate the degradation progression and remaining operational lifetime of the system. The stacking ensemble strategy is adopted to exploit the complementary strengths of multiple learning algorithms with different inductive biases, thereby improving prediction accuracy and robustness. The proposed ensemble model consists of two base regression learners and a meta-learner (final estimator). The base models are trained independently using the original feature set, and their predictions are subsequently combined by the meta-learner to produce the final RUL estimate. This hierarchical learning structure enables the model to capture both nonlinear feature interactions and stable global trends in the degradation process.

2.3. Base Regression Models

2.3.1. Extra Trees Regressor

The first base learner employed in the stacking ensemble is the Extra Trees Regressor (Extremely Randomized Trees). This model is an ensemble of decision trees that introduces a high degree of randomness in both feature selection and split point determination. Such randomness improves generalization performance, particularly in high-dimensional and noisy feature spaces commonly encountered in vibration-based condition monitoring. The primary role of the Extra Trees Regressor in the proposed framework is to generate fast and stable RUL predictions while reducing the risk of overfitting. By averaging predictions across a large number of randomly constructed trees, the model effectively captures global patterns in the degradation data.

The Extra Trees Regressor is configured with the following hyperparameters:

- Number of trees: $n\_estimators = 400$
- Maximum tree depth: $max\_depth = 25$
- Random seed: $random\_state = 42$

These hyperparameter values were selected to balance prediction accuracy and computational efficiency while ensuring reproducibility.

2.3.2. XGBoost Regressor

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The second base learner in the ensemble is the Extreme Gradient Boosting (XGBoost) Regressor, a powerful gradient boosting algorithm widely used for modeling complex nonlinear relationships. XGBoost constructs an additive ensemble of decision trees in a sequential manner, where each new tree aims to correct the residual errors of the previous ones. In the context of RUL prediction, the XGBoost Regressor plays a crucial role in learning complex degradation dynamics, particularly those arising from temporal dependencies introduced by lagged and smoothed features. Its ability to handle nonlinear interactions and varying feature importance makes it well suited for modeling progressive gearbox degradation [8].

The XGBoost Regressor is implemented with the following hyperparameters:

- Number of boosting iterations: $n\_estimators = 500$
- Learning rate: $learning\_rate = 0.03$
- Maximum tree depth: $max\_depth = 10$
- Random seed: $random\_state = 42$

A relatively small learning rate combined with a larger number of boosting iterations is employed to ensure stable convergence and improved generalization.

2.4. Meta-Learner: Ridge Regression

The final stage of the stacking ensemble employs Ridge Regression with cross-validation (RidgeCV) as the meta-learner [9]. The meta-learner takes the RUL predictions generated by the Extra Trees and XGBoost regressors as input features and produces the final RUL estimate. Ridge Regression is selected due to its linear formulation and the inclusion of L2 regularization, which mitigates overfitting by penalizing large regression coefficients. This property is particularly important when combining predictions from multiple base models, as it prevents any single learner from dominating the final prediction. The RidgeCV implementation automatically determines the optimal regularization parameter (α) through cross-validation, ensuring an appropriate balance between bias and variance without manual hyperparameter tuning. By learning an optimal weighted combination of base model outputs, the meta-learner enhances prediction stability and overall RUL estimation accuracy.

2.5. Evaluation Metrics for RUL Prediction

The performance of the proposed stacking ensemble regressor for remaining useful life (RUL) prediction is quantitatively evaluated using three widely adopted regression metrics: Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and the coefficient of determination (R^2). These metrics provide complementary insights into the prediction accuracy, robustness, and goodness-of-fit of the regression model. Let $y_i$denote the true RUL value of the i-th sample, $\hat{y}_i$the corresponding predicted RUL value, and $N$the total number of samples in the test set [10]. The evaluation metrics are defined as follows:

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$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2} \quad (1)$$

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{N} | y_i - \hat{y}_i | \quad (2)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{N}(y_i - \bar{y})^2} \quad (3)$$

where $\bar{y}$represents the mean of the true RUL values. Lower values of RMSE and MAE indicate higher prediction accuracy, while an R^2value closer to unity signifies a stronger agreement between predicted and actual RUL values.

3. Results and Discussion

Figure 1 illustrates the relationship between the actual RUL values and the corresponding predictions generated by the proposed stacking ensemble regressor. Each point in the scatter plot represents an individual test sample, where the horizontal axis denotes the true RUL expressed as a percentage of life consumption, and the vertical axis indicates the predicted RUL. The dashed diagonal line corresponds to the ideal prediction line ($y = x$), representing perfect agreement between predicted and actual values. As shown in Figure 1, the majority of the predicted RUL values are distributed closely around the ideal diagonal line, indicating a strong correlation between the model predictions and the true RUL values across different degradation stages. This alignment demonstrates the effectiveness of the stacking ensemble approach in capturing the underlying degradation trend of the gearbox system. Some dispersion is observed, particularly at lower and intermediate RUL ranges, which can be attributed to measurement noise, feature uncertainty, and the inherent complexity of degradation dynamics. Nevertheless, the overall distribution confirms that the proposed model provides accurate and consistent RUL estimates over the entire lifespan, validating its suitability for practical prognostics and health management applications.

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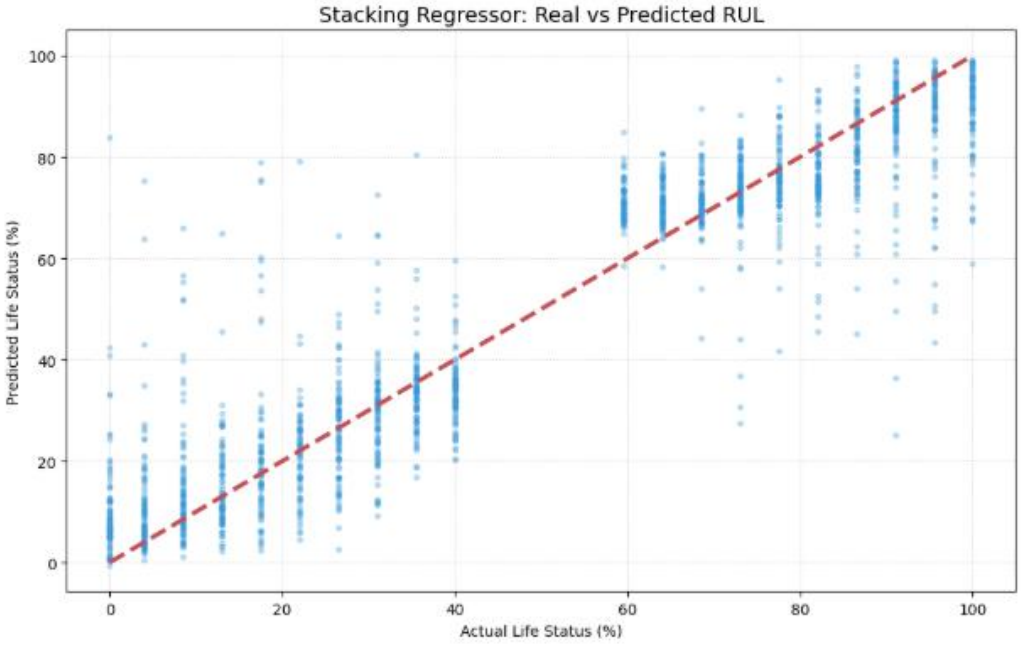

Figure 1. Comparison of actual and predicted remaining useful life (RUL) values using the stacking ensemble regressor

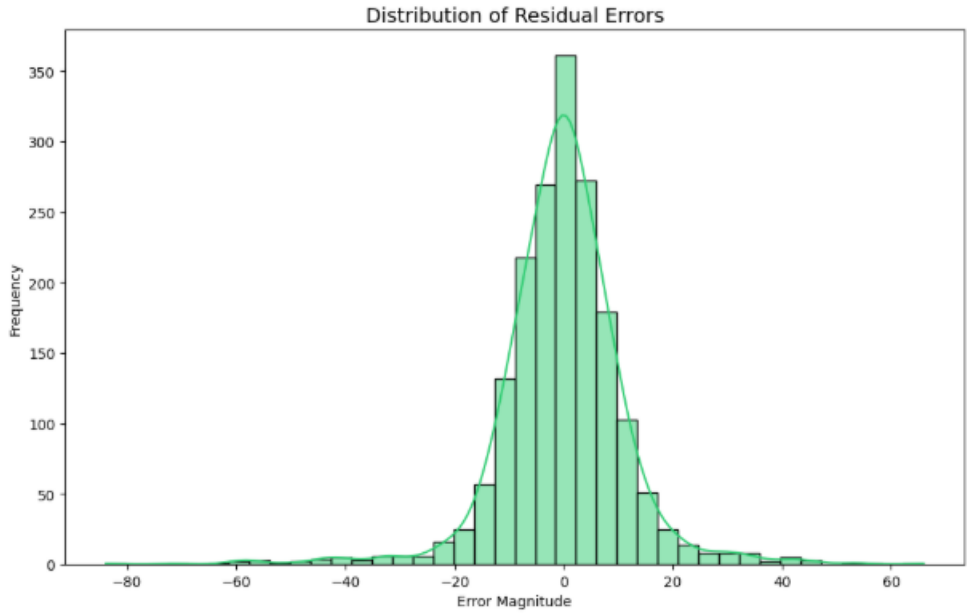

Figure 2. Distribution of residual errors for the stacking ensemble regressor in RUL prediction

Figure 2 presents the distribution of residual errors, defined as the difference between the predicted and actual remaining useful life (RUL) values, obtained from the proposed stacking ensemble regressor. The histogram illustrates the frequency of error magnitudes across the test dataset, while the overlaid density curve highlights the overall error distribution pattern.

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As observed in Figure 2, the residual errors are centered around zero and exhibit an approximately symmetric, bell-shaped distribution, indicating that the model predictions are largely unbiased. The concentration of errors near zero demonstrates that the majority of RUL estimates deviate only slightly from the true values, reflecting high prediction accuracy. The presence of relatively small tails on both sides of the distribution suggests that larger overestimations or underestimations occur infrequently and can be attributed to noise in the vibration features, variability in degradation behavior, or inherent uncertainties in RUL labeling.

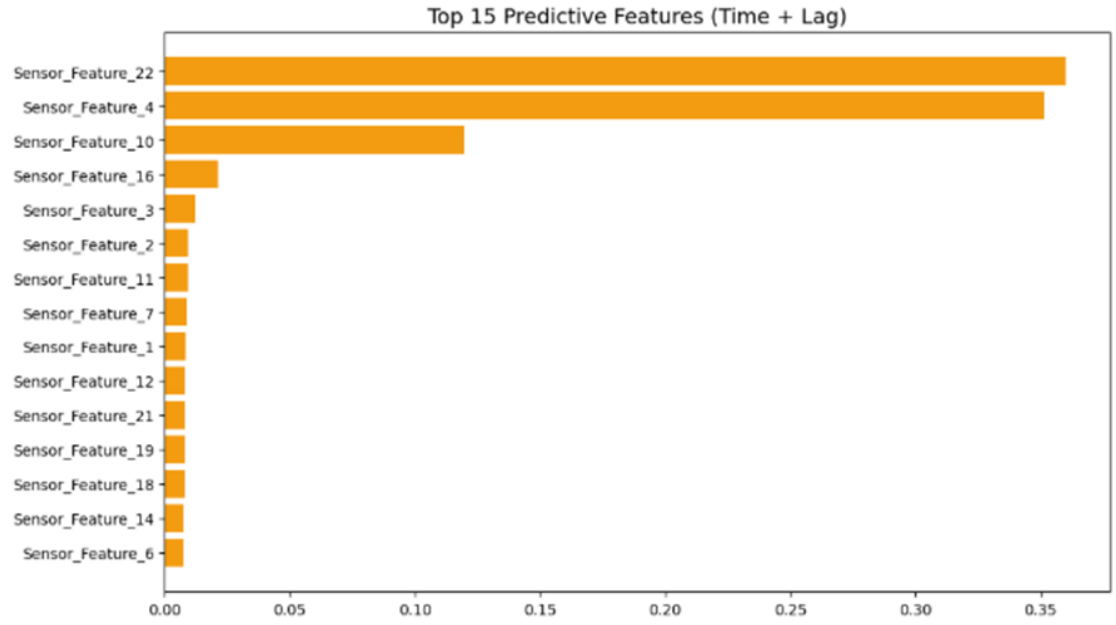

Figure 3. Top predictive features for RUL estimation based on time-domain and lagged vibration features

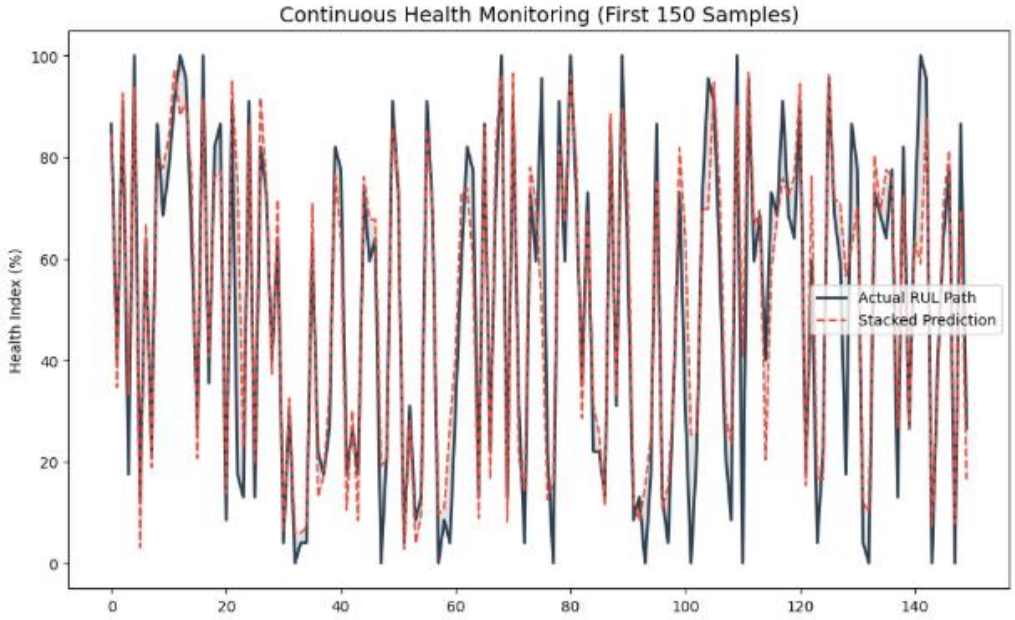

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Figure 4. Continuous health monitoring based on actual and predicted RUL trajectories

Figure 3 illustrates the relative importance of the top 15 predictive features contributing to the remaining useful life (RUL) estimation obtained from the proposed stacking ensemble regressor. The feature importance scores reflect the contribution of each time-domain and lag-based sensor feature to the overall predictive performance of the model. As shown in Figure 3, a small subset of features dominates the RUL prediction, with *Sensor_Feature_22*, *Sensor_Feature_4*, and *Sensor_Feature_10* exhibiting significantly higher importance scores compared to the remaining features. This indicates that these features capture critical degradation-related information and play a key role in characterizing the gearbox health evolution. The remaining features contribute incrementally to the prediction performance, suggesting that the ensemble model effectively leverages both dominant and complementary information from multiple sensors and lagged representations. The observed feature importance distribution demonstrates the ability of the stacking ensemble approach to perform implicit feature selection, emphasizing the most informative degradation indicators while suppressing less relevant or redundant features. This behavior enhances model interpretability and supports the physical plausibility of the RUL prediction results, as degradation processes in mechanical systems are often driven by a limited number of sensitive condition indicators.

Figure 4 illustrates the continuous health monitoring performance of the proposed stacking ensemble regressor over the first 150 samples of the test sequence. The solid black curve represents the actual RUL (health index) trajectory, while the dashed red curve corresponds to the RUL values predicted by the stacking ensemble model. As shown in Figure 4, the predicted RUL closely follows the overall trend of the actual health degradation path, demonstrating the model's capability to track dynamic changes in system health over time. Despite the presence of short-term fluctuations and abrupt variations in the actual RUL signal—which are common in vibration-based condition monitoring—the predicted trajectory maintains a strong temporal alignment with the true health index. This indicates that the model effectively captures both global degradation patterns and local variations in the health evolution process. The slight deviations observed at certain time instances can be attributed to noise in the sensor measurements, uncertainty in feature extraction, and the inherent complexity of degradation dynamics. Nevertheless, the close agreement between actual and predicted RUL trajectories confirms the suitability of the proposed stacking ensemble approach for continuous health monitoring and real-time prognostics of gearbox systems.

Table 2. Performance evaluation metrics for RUL prediction using the stacking ensemble regressor

Metric	**Value**
MAE	7.7997
RMSE	11.5621
R^2 Score	0.8750

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Table 2 reports the quantitative performance of the proposed stacking ensemble regressor for remaining useful life (RUL) prediction on the test dataset. The Mean Absolute Error (MAE) of 7.7997 indicates that, on average, the predicted RUL values deviate from the true RUL by approximately eight units, demonstrating a relatively low typical prediction error. The Root Mean Square Error (RMSE) of 11.5621, which penalizes larger errors more heavily, suggests that while some larger deviations occur, they remain limited and do not dominate the overall prediction performance. The coefficient of determination (R^2 = 0.8750) shows that approximately 87.5% of the variance in the true RUL values is explained by the proposed model. This high R^2 value confirms a strong agreement between predicted and actual degradation behavior, indicating that the stacking ensemble effectively captures the underlying degradation dynamics of the gearbox system. Overall, these results demonstrate that the proposed approach provides accurate, stable, and reliable RUL estimates, making it suitable for practical prognostics and health management applications.

4. Conclusion

This study presented a data-driven framework for remaining useful life (RUL) prediction of gearbox systems using a stacking ensemble regressor built upon vibration-based condition monitoring features. Statistical, lag-based, and smoothed features extracted from multi-sensor vibration signals were utilized to capture both instantaneous and temporal degradation characteristics. By integrating heterogeneous learning models with complementary strengths, the proposed stacking ensemble approach aimed to improve prediction accuracy and robustness compared to single-model regressors. The ensemble architecture combined Extra Trees and XGBoost regressors as base learners, while Ridge Regression was employed as a meta-learner to fuse their predictions in a regularized and stable manner. Experimental results demonstrated that the proposed method achieved strong predictive performance, with an MAE of 7.7997, an RMSE of 11.5621, and an R^2score of 0.8750. These results indicate that the model is capable of accurately tracking the degradation process and explaining a substantial proportion of the variance in true RUL values. The analysis of predicted versus actual RUL trajectories and residual error distributions further confirmed the stability, low bias, and reliability of the proposed approach across different degradation stages. In addition, feature importance analysis revealed that a limited subset of time-domain and lagged vibration features plays a dominant role in RUL estimation, enhancing the interpretability of the model and supporting its physical relevance to gearbox degradation mechanisms. The continuous health monitoring results demonstrated that the stacking ensemble regressor can effectively follow the temporal evolution of system health, making it suitable for real-time prognostics and health management applications.

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EFFECTS OF ORGANIC FERTILIZERS ON PLANT GROWTH AND YIELD COMPONENTS IN KAPIA PEPPER PRODUCTION

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ABSTRACT

This study was conducted to determine the effects of different organic fertilizers on plant development and yield in kapia peppers in Denizyaka location of Manavgat district, Antalya province in a field where commercial plants were not previously grown, during periods January-August 2025 vegetable growing season. The Elzem F_1 kapia pepper variety, widely cultivated in study region, was used as plant material. Following nine fertlizer applications were reseached: 1- farmer practice (Control), 2- standard application (N, P, K, Ca, Mg) (Control), 3- chicken manure, 4- sheep manure, 5- cattle manure, 6- pigeon manure, 7- bat guano, 8- seaweed fertilizer and 9- worm manure (vermicompost). The research was established according to a randomized complete block design with 4 replications. Seedlings were planted at spacing of 100 cm between rows and 20 cm within rows. Each plot had an area 4 m² and contained 20 plants per each replication. According to the research, among the organic fertilizers applied to kapia peppers, those used by plant growers had a positive effect. In study, results of sheep manure (4038,07 kg/da) and cattle manure (2990,75 kg/da) were in separate groups, while other organic fertilizers were in an intermediate group. The effects of organic fertilizers, particularly vermicompost, were prominent in plants with fruit-related characteristics.

Keywords: *Capsicum annuum L.*, kapia pepper, organic agriculture, animal manures, plant growth, yield.

1. INTRODUCTION

Organic farming is an important production method prioritizİNG human health by adhering to principles based on protecting nature. Vegetable production worldwide is increasing day by day as a result of rapid population growth and desire for healthy and balanced nutrition. Peppers are one such vegetable and are extremely important for organic farming. Kapia pepper is a

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vegetable known as *Capsicum annuum* L. var. *conoides (Mill.) Irish*. within the Capsicum genus of the nightshade family (*Solanaceae*).

According to Food, B. M., & Organization, T. (2020). Food and Agriculture Organization of the United Nations, 36,136,673 tons of peppers were produced on 2,069,990 hectares of land worldwide in 2020. The leading producer countries are China (46.08%), Mexico (7.8%), Indonesia (7.67%), Türkiye (7.3%), and Spain (4.07%), accounting for 72.92% of global pepper production.

In accordance of Turkish Statistical Institute (TUİK) 2025 data, 3,318,000 tons of peppers were produced in Türkiye on an area of 762,234 hectares. Within this production, kapia peppers accounted for 1,818,000 tons, bell peppers 426,000 tons, pointed peppers 944,500 tons, and charleston peppers 129,500 tons. Türkiye is one of the most important pepper-producing countries in world general (TUİK, 2025).

The use of chemical fertilizers is one of the important tools that increase yield and quality of crops. However, unbalanced use of these fertilizers may lead to deteriorations on physical, chemical, and biological properties of the soil, and can exert notable effects on parameters related to plant yield, disease resistance, and human health. Moreover, beyond their impact on soil and plants, chemical fertilizers also contaminate groundwater and surface water resources contributing to major environmental problems. Because of these negative aspects, people are turning to organic farming and organically grown products. This situation increases the importance of adopting sustainable practices and more environmentally friendly methods in the agricultural sector (Ngouajio et al., 2003; Kılıç and Korkmaz, 2012; Wang et al., 2021). The use of reasonable combinations of organic and inorganic fertilizer sources is necessary not only to protect soil health but also to sustain productivity (Gokul et al., 2020). Organic farming aims to protect environment, people, and animals. Because the most important goal is to leave a clean environment and soil for future generations without causing ecological problems through organic farming methods that are in harmony with nature (Duman and Elmacı, 2014).

Archaeological findings from Native American sites reveal that *Capsicum* has been valued as a food source, spice, medicine, and even decorative item since 7000 BC (Yaldız, 2008). Peppers are widely used in industry as well as being consumed fresh, in the form of sauces, pickles, pastes, powdered and flaked peppers, dried and roasted peppers, etc. Many types of *Capsicum*, which have a remarkable effect on human health due to their oil, pigments, resin, protein, cellulose, and mineral content, are also sources of vitamin E and provitamin A (carotene). Capsaicin ($C_{18}H_{27}NO_3$), an alkaloid responsible for pungency in peppers, is known to have several health-related effects. Studies have shown that capsaicin inhibits the development of cancerous cells; regions with high consumption of hot peppers have lower cancer rates, particularly for colon, stomach, and circulatory system cancers (Archer and Jones, 2002, Vural et al., 2000; Şalk et al., 2008). Research has shown that capsaicin, a compound found in chili peppers can potentially be used as an agent that blocks factors causing oxidative stress in cells and leading to obesity (Leung, 2008).

In agricultural production activities, the ability of a plant to develop well in the soil is related to the physical, chemical, and biological properties of the soil environment in which it grows.

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The most commonly used method for improving the physical, chemical, and biological properties of soil is the addition of organic materials (Koç, 2008). Among the most notable benefits of organic fertilizers for soil and plant growth are their contributions to soil aggregation, reduced erosion risk, improved water-holding and aeration capacity of soils, and consequently enhancing plant development (Mercik and Stepien, 2006). Organic fertilizers make the soil easier to cultivate and promote plant root development.

Organic vegetable production involves various materials of organic origin, different animal fertilizers and their dosages, and theses and/or research methods aimed at determining optimal dosages. For example; broccoli (Karakaya and Paksoy, 2008); cauliflower (Kıl and Paksoy, 2016 and Yardım, 2025); lettuce (Ali et al., 2007; Adiloğlu et al., 2018; Durak et al., 2017; Çıtak et al., 2011); tomato (Sönmez et al., 2019); garlic (Kenea and Gedamu, 2018), chard (Köksal et al., 2017) and pepper (Gürpınar and Mordoğan, 2005; Kır and Mordoğan, 2006; Del amor, 2006; Kır, 2006; Delate et al., 2008; Llaven et al., 2008; Szafirowska and Elkner, 2008; Berova et al., 2010; Bozkurt (2019) from Appiredy et al., 2011; Márquez-Quiroz et al., 2012; 2013; Ghimire et al., 2013; Duman and Elmacı, 2014; Funsho et al., 2015; Shiva et al., 2015; Alaboz et al., 2017; Dominic Studies have been conducted by (et al., 2017; Sahoo et al., 2017; Rekha et al., 2018; Bozkurt, 2019) to determine the effects of organic fertilizers on seedling and plant development, yield, and quality. Many more studies could be mentioned here. However, the effectiveness and reliability of the recommended doses have been a subject of debate in conversations with farmers. All these changes were based on the recommended doses of an organic material used in this study. There was a need to determine the yields in the organic units used in these dispensers in kapia peppers.

This study aimed to determine the effects of certain organic fertilizers, used at recommended doses in kapia pepper cultivation-a significant industrial product that plays an important role in human nutrition-on plant growth and yield components.

2. MATERIALS AND METHODS

The research was conducted in the 2025 vegetable growing season (between January and August) on a field in Denizyaka neighborhood situated at Manavgat district, Antalya where commercial crops have not been grown before, to determine the effects of different organic fertilizers on plant growth and yield components of kapia peppers.

The climate of the research area is typical Mediterranean, with hot and dry summers and mild and rainy winters. The average temperature in the hottest months of the year, July and August, is around 29.0 °C. The annual average relative humidity is around 64% (Anonymous, 2024). The experimental field in Denizyaka is located at 36.85° latitude and 31.18° longitude and is approximately 6 m above sea level. The soil at the trial site has been analyzed and found to be clayey-loamy with a neutral pH. The climate during the growing season and the soil at the research site are considered suitable for pepper cultivation.

As plant material, the Elzem F1 kapia pepper cultivar, which is well known in the region, was used. In this study, nine treatments mentioned below were included:

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1- Farmer practice (ÇU), 2 -Technical application (TU; applied as 20 kg/da N, 10 kg/da P_2O_5, 25 kg/da K_2O, 10 kg/da Ca, and 5 kg/da Mg as pure nutrients), 3- Chicken manure (TG; 2000 kg/da), 4- Sheep manure (KG; 5000 kg/da), 5- Cattle manure (İG; 5000 kg/da), 6- Pigeon manure (GG; 150 kg/da), 7- Bat manure (guano) (YG; 150 kg/da), 8- Seaweed fertilizer (DYG; 1 L seaweed extract diluted in 200 L water and applied per decare), 9- worm manure (vermicompost) (SG; 200 kg/da).

The research plots were established in a randomized block design with four replicates. Seedlings were planted with 100 cm between rows and 20 cm within rows. Plot size was 4 m^2, and each replicate contained 20 plants. All fertilizers were thoroughly mixed into the soil at predetermined rates prior to planting the seedlings.

Kapia pepper seeds were sown into 216-cell trays in seedling nurseries, and seedlings were grown under appropriate conditions, becoming ready for transplanting in approximately 48 days. The seedlings were transplanted to the field at the end of April. In addition, soil preparation of the land where the experiment would be established (plowing, thinning - leveling, and sampling of the plots) was carried out in April before the seedlings were planted. The experiment consisted of 9 treatments and 4 replications, resulting in a total of 36 plots. Twenty plants were transplanted into each plot at 100 cm × 20 cm spacing.

The plants were cultivated in accordance with the standard kapia pepper growing practices. During the production period, plant protection measures were implemented using only the pesticides and preparations permitted by the relevant regulations for controlling diseases and pests. In the kapia pepper plants, vegetative growth parameters including plant height (cm), stem diameter (cm), number of leaves (count), leaf length (cm), leaf width (cm), root length (cm), stem fresh and dry weight (g), and root fresh and dry weight (g) were measured and recorded. In addition, generative characteristics were assessed by determining total yield (kg/da), fruit diameter (cm), fruit flesh thickness (mm), fruit length (cm), fruit weight (g), soluble solid content (%), and fruit fresh and dry weight (g).

The data obtained from the study were grouped according to significant differences between treatments at a 5% significance level using the JMP 14.0 statistical program, based on the randomized block design.

3. RESULTS AND DISCUSSION

The results obtained from different organic fertilizer applications on plant growth and yield parameters in kapia pepper cultivation are presented in Tables 1, 2, and 3.

In Table 1, the effect of organic fertilizers applied to kapia peppers on plant height was found to be statistically significant; the longest plant height was obtained from cattle manure (63,25 cm) and worm manure (62,75 cm) applications. Other fertilizer applications resulted in lower plant heights and formed a separate group. These results are similar to Yaldız (2008)'s findings of 51,2-94,98 cm and Karaağaç and Balkaya (2010)'s findings of 50,10-59,40 cm, as well as the findings of Tajungsola et al. (2017) (44,55 cm).

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The thickest stem diameter was observed in the vermicompost treatment (4,82 mm), whereas the thinnest stem diameter occurred in the pigeon manure treatment (4,05 mm). The remaining treatments was between these two groups.

The effects of different fertilizer applications on the number and diameter of leaves in kapia peppers were not statistically significant (Table 1). These results were lower than those reported by Tajungsola et al. (2017) (35,97 leaves). This may be due to the different varieties used.

Table 1. Effects of Different Organic and Chemical Fertilizers on Plant Growth in Kapia Pepper

Treatments	**Plant height (cm)**	**Stem diameter (mm)**	**Number of leaves (units)**	**Leaf length (cm)**	**Leaf width (cm)**
Farmer's Practice (FP)	54,75b	4,41ab	105,00a	9,50a	4,50a
Technical Practice (TP)	53,75b	4,55ab	108,25a	9,25a	4,75a
Chicken Manure (CM)	56,50b	4,28ab	102,25a	7,75b	4,75a
Sheep Manure (SM)	57,25b	4,35ab	108,25a	9,50a	4,50a
Cattle Manure (CM)	63,25a	4,52ab	108,25a	9,50a	5,00a
Pigeon Manure (PM)	56,75b	4,05b	101,25a	8,50ab	4,25a
Bat Manure (BM)	54,25b	4,11b	107,25a	9,00ab	4,25a
Seaweed Fertilizer (SF)	57,25b	4,20ab	106,00a	8,75ab	4,25a
Vermicompost (VC)	62,75a	4,82a	108,00a	9,50a	4,75a
LSD 0.05	5.11	0.66	10.12	1.35	0.90

Leaf length, however, was found to be statistically significant. The longest leaves were obtained from the farmer practice, NPKCaMg, sheep manure, cattle manure, and vermicompost treatments, whereas the shortest leaves were observed in the chicken manure treatment. The other treatments were grouped between these two extremes.

As seen Table 2, root length was statistically significant according to the applied fertilizers; the longest root length was observed in the vermicompost application at 31,25 cm, while the shortest root length was found in the seaweed fertilizer application at 24,25 cm. Other applications were between these two groups.

Stem fresh weight differed significantly among treatments (Table 2). The highest stem fresh weights were found in the sheep, cattle, and vermicompost applications, while the lowest were

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recorded in the farmer practice, chicken manure, pigeon manure, and seaweed fertilizer treatments.

Stem dry weight was found to be statistically significant (Table 2). The highest stem dry weight was obtained from sheep, cattle and vermicompost applications, forming a separate group from the other applications. Other applications were in the second group with lower stem weights.

The effects of different fertilizers applied to kapia peppers on root fresh weight were found to be statistically significant (Table 2). When examining root fresh weight values, the maximum root fresh weights were obtained from cattle manure, sheep manure, and worm compost applications with values of 50,25 – 49,00 g, and 45,50 g, respectively, and were statistically grouped together. The lowest root fresh weights were obtained from seaweed and bat guano applications with values of 33,00 g and 29,75 g.

The effects of different fertilizers applied to kapia peppers on root dry weight were found to be statistically significant (Table 2). When root dry weight values were examined, the highest root dry weight was 14,25 g in sheep manure, while the minimum root dry weight was 9,50 g in bat manure, forming two separate groups. Other applications were in the intermediate group with lower root dry weights.

Table 2. Effect of different organic and chemical fertilizers applications on plant development of kapia peppers

Treatments	**Root length (cm)**	**Shoot fresh weight (g)**	**Shoot dry weight (g)**	**Root fresh weight (g)**	**Root dry weight (g)**
Farmer's Practice (FP)	28,00abc	101,25c	50,75b	37,00cd	13,50abc
Technical Practice (TP)	30,00ab	110,75b	55,25b	41,50bc	12,00abcd
Chicken Manure (CM)	26,75bc	101,25c	52,50b	41,00bc	11,50bcd
Sheep Manure (SM)	30,25ab	119,25a	61,25a	49,00a	14,25a
Cattle Manure (CM)	30,25ab	121,25a	63,50a	50,25a	14,00ab
Pigeon Manure (PM)	26,75bc	96,00c	55,25b	37,00cd	11,25cd
Bat Manure (BM)	30,00ab	103,00bc	53,00b	29,75e	9,50d
Seaweed Fertilizer (SF)	24,25c	99,50c	52,75b	33,00de	11,50bcd
Vermicompost (VC)	31,25a	122,75a	62,75a	45,50ab	13,50abc
LSD 0.05	4.01	8.20	5.53	7.22	2.54

The effects of different organic–animal manure treatments on yield components were evaluated, and the results are presented in Table 3.

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Total highest yield was obtained from sheep manure treatment (4038,07 kg/da) and lowest in the cattle manure treatment (2990,75 kg/da). Other treatments were distributed between these two groups. These findings are consistent with those reported by Duman and Elmacı (2014) and Kır (2006).

Average fruit weight was the highest with vermicompost (122,50 g/fruit) and was in a separate group. Other treatments produced lower values. These results were lower than those reported by Jamir et al. (2017) (140,47 g/fruit), possibly due to differences in cultivars and growing conditions. They are similar to the findings of Çiftçi et al. (2023), which ranged from 93,57 to 158,21 g/fruit.

Table 3. Effects of different organic and chemical fertilizers on yield and yield components in kapia pepper

Treatments	**Total Yield (kg/da)**	**Avg. Fruit Weight (g)**	**Avg. Fruit Length (cm)**	**Avg. Fruit Diameter (cm)**	**Fruit Flesh Thickness (mm)**	**Total Soluble Solids (%)**	**Fruit Fresh Weight (g)**	**Fruit Dry Weight (g)**
Farmer's Practice (FP)	3869,40ab	94,50c	18,30cd	4,12 cd	3,50 e	4,58bc	94,50c	45,00cd
Technical Practice (TP)	3690,85ab	111,50ab	19,03abc	4,30 b	3,47 e	5,10a	111,50ab	53,50ab
Chicken Manure (CM)	3857,84ab	75,00d	18,85bcd	4,25 bc	3,67 d	5,18a	75,00d	38,00de
Sheep Manure (SM)	4038,07a	103,75bc	20,00a	5,05 a	4,57 ab	5,53a	103,75bc	50,75bc
Cattle Manure (CM)	2990,75b	115,75ab	19,63ab	4,93 a	4,50 b	5,50a	115,75ab	56,50ab
Pigeon Manure (PM)	3892,40ab	66,75d	18,13cd	4,07 d	4,25 c	5,18a	66,75d	35,75e
Bat Manure (BM)	3521,13ab	74,25d	18,00d	4,12 cd	3,70 d	5,08ab	74,25d	37,00e
Seaweed Fertilizer (SF)	3622,75ab	73,25d	18,10cd	4,12 cd	4,17 c	4,45c	73,25d	36,25e
Vermicompost (VC)	3975,17ab	122,50a	19,08abc	5,05 a	4,70 a	5,55a	119,50a	59,50a
LSD 0.05	1033.6	12.25	1.00	0,14	0,13	0.52	12.25	7.05

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Average fruit length was highest in the sheep manure treatment (20,00 cm) and lowest in the bat guano treatment (18,00 cm). The remaining treatments were grouped between these values. These results are in agreement with Çiftçi et al. (2023) (14,85–18,49 cm). On the other hand, they were lower than the values reported by Jamir et al. (2017) (7,50 cm), likely due to differences in cultivar characteristics or environmental conditions.

When the mean fruit diameter values were examined, the highest average fruit diameters were obtained from the sheep manure and vermicompost treatments with 5,05 cm, followed by the cattle manure treatment with 4,93 cm, and these applications were found to be within the same statistical group. The lowest fruit diameter was recorded in the pigeon manure treatment with 4,07 cm. These results were lower than the mean fruit diameters reported by Çiftçi et al. (2023), which ranged between 59,01–75,17 mm. This difference is likely due to varietal characteristics and differences in environmental and cultivation conditions.

Regarding mean fruit flesh thickness, the highest value was obtained from the vermicompost treatment (4,70 mm), which formed a separate statistical group. The other fertilizer treatments resulted in lower flesh thickness values and were placed in different groups from vermicompost. The lowest fruit flesh thickness values were recorded in the farmer practice and technical application treatments with 3,50 mm and 3,47 mm, respectively, and these treatments constituted a distinct group. Fruit flesh thickness values reported by Karaağaç and Balkaya (2010) for Bafra red pepper populations [*Capsicum annuum* L. var. *conoides* (Mill.) Irish] ranged between 3,3–5,8 mm. The fruit flesh thickness values of the cultivar examined in the present study are consistent with the findings of Karaağaç and Balkaya (2010).

The soluble solid content was lowest in the seaweed fertilizer treatment, forming a separate statistical group from the others. These findings were lower than the soluble solid content values (7.57–8.33%) reported by Çiftçi et al. (2023). This variation may again be attributed to cultivar differences or environmental conditions.

Fruit fresh weight was highest in the vermicompost treatment, which formed a distinct group, whereas the lowest fruit fresh weights were obtained from the chicken manure, pigeon manure, bat guano, and seaweed fertilizer treatments.

Similarly, vermicompost ranked first in fruit dry weight and constituted a separate group, while the other treatments led to lower fruit dry weights.

4. RECOMMENDATIONS

The results clearly show that worm manure (vermicompost) stand out in many parameters. By considering the beneficial impacts of vermicompost on both vegetative growth (plant height, stem diameter, root development) and generative characteristics (fruit weight, fruit diameter, fruit flesh thickness, soluble solid content, and fresh and dry fruit weight), it can be inferred that vermicompost represents a viable and sustainable nutrient source for kapia pepper cultivation. Therefore, it can be highly recommended to growers aiming for quality-oriented kapia pepper production incorporate vermicompost into their fertilization programs.

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AN ALTERNATIVE AGRICULTURAL PRODUCTION MODEL: AGRIVOLTAIC SYSTEMS

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Abstract

The global agricultural sector requires an uninterrupted energy supply to ensure food security, mechanization, and the sustainability of modern irrigation techniques. However, fossil fuels, which dominate the traditional energy portfolio, have become a major risk factor due to resource scarcity, geopolitical price instabilities, and devastating environmental impacts on the ecosystem. In this context, the transition to renewable sources such as solar energy is not merely an environmental preference but a strategic necessity for establishing energy security and the economic resilience of agricultural enterprises. This transformation, at the heart of climate change mitigation strategies, acts as a catalyst for achieving sustainable development goals. Today, increasing demographic pressure and rapid urbanization lead to the narrowing of arable land, triggering intense land-use competition between the energy and food sectors. At this point, Agrivoltaic (APV) systems, which emerge as a solution optimizing the "Food-Energy-Water" nexus, eliminate the existing land-use conflict. APV technology maximizes total land productivity by allowing the simultaneous execution of photovoltaic energy production and agricultural activities on the same land unit. The primary purpose of this study is to conduct a comprehensive evaluation of APV systems as a sustainable production model by analyzing their technological synergy and application potential within the agricultural sector. The primary material of this study consists of data obtained from the current databases, strategic plans, and sectoral reports of globally and nationally recognized authorities, such as the Republic of Türkiye Ministry of Energy and Natural Resources (MENR), the Ministry of Agriculture and Forestry (MAF), the International Energy Agency (IEA) and Ember. Within the scope of the study, research results in the literature regarding the technical parameters and application models of agrivoltaic systems were utilized. The collected statistical data and technical information were organized through explanatory figures and interpreted accordingly.

Keywords: agrivoltaics, renewable energy, sustainable agriculture, land productivity.

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1. INTRODUCTION

Energy is the fundamental building block of modern societies and economies. Türkiye is an energy-dependent country, importing more than half of its energy needs. This dependency poses a significant economic risk due to geopolitical hazards, economic fluctuations, and supply disruptions. Reducing energy costs and ensuring energy security are among the country's primary objectives (Arı and Yılmaz, 2023). While energy is critically important across all sectors, it has a direct impact on costs in the agricultural sector due to intensive operations such as irrigation and mechanization. This situation necessitates energy efficiency and the use of renewable energy sources, particularly for small and medium-sized agricultural enterprises. Furthermore, in line with global targets to limit the average temperature increase (Paris Agreement), countries prefer renewable energy sources over traditional fossil fuels. In this context, the popularity and capacity of solar energy have been increasing rapidly in recent years in countries like Türkiye, which has high solar energy potential (Ember, 2023).

The widespread adoption of Photovoltaic (PV) systems due to their cost-effectiveness brings a new challenge to the agenda. PV is the technology of converting solar energy into electric current. In PV systems, semiconductors such as silicon, gallium arsenide, cadmium telluride, or copper indium diselenide are used, and these are rare materials. These types of materials have the property of directly converting solar energy into electrical energy. Increasing global population and urbanization are leading to a scarcity of arable land, predicting a future land-use competition between energy production and food production. As a solution to this land-use conflict, Agrivoltaic (APV) systems have been proposed, which provide economic benefits by enabling both energy production and agricultural activities on the same piece of land. APV refers to the integration of PV module installation with agricultural production (Waghmare et al., 2023).

2. PURPOSE AND METHODS

The primary purpose of this study is to conduct a comprehensive evaluation of APV systems as a sustainable production model by analyzing their technological synergy and application potential within the agricultural sector. In this context, the research aims to detail the integration of photovoltaic energy production with agricultural activities through the examination of both global application examples and local potential models. The main material of the study consists of data obtained from the current databases, strategic plans, and sectoral reports of nationally and globally recognized authorities, such as the Republic of Türkiye Ministry of Energy and Natural Resources (MENR), the Ministry of Agriculture and Forestry (MAF), the International Energy Agency (IEA) and Ember.

In addition to these sources, previous research results in the literature regarding the technical parameters and application models of agrivoltaic systems were utilized. The collected statistical data and technical information were evaluated and interpreted through explanatory figures.

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3. RESULTS

3.1. Energy Production in the World and Türkiye

Global energy production is steadily increasing due to the effects of robust economic growth, rapid population expansion, and industrialization processes. For instance, in 2024, global electricity generation exceeded 31,229 TWh (Terawatt-hours). Fossil fuels account for the largest share of production at approximately 59%. Within this share, coal (35%), natural gas (22%), and oil (2%) continue to have a significant impact. Nevertheless, renewable energy sources maintain their share in the energy mix, accounting for approximately 32% of total production. Record increases in the production of solar energy (approximately 7%) and wind energy (approximately 8%) have been strongly supported by technological advancements and falling costs in this field (IEA, 2025).

The upward trend in Türkiye's energy production and consumption continues alongside rising electricity demand. In 2024, electricity consumption reached approximately 348 TWh. Although fossil fuels remain dominant in the distribution of production sources, their share has declined to 55%, the lowest level since 1993. Coal continues to be the primary fossil source with a share of approximately 36%, and 61% of this coal-based production relies on imports. On the other hand, the share of renewable energy sources in total electricity generation has increased significantly to 46%. The transition to clean energy has accelerated, especially with the strong contribution of hydroelectric, wind, and solar energy; in fact, the amount of energy produced by wind and solar combined has surpassed the amount obtained from domestic coal for the second consecutive time. While these developments indicate strong steps toward sustainable energy production, the role of fossil fuels in meeting increasing demand has not yet fully diminished (MENR, 2024; SHURA, 2025; Ember, 2025).

3.2. General Information on APV Systems

3.2.1. Definition and characteristics of APV systems

The concept of APV was first proposed in 1982 by Goetzberger and Zastrow with the aim of adapting solar power plants to enable agricultural production on the same land (Goetzberger and Zastrow, 1982). This approach involves elevating solar panels approximately two meters above the ground and increasing the distance between the panels to prevent excessive shading of the crops. It was envisioned that the proposed system would utilize only one-third of the incoming solar radiation and could be made more suitable for agricultural production through technical improvements. However, the application of this concept to actual projects and pilot plants took approximately thirty years (Dinesh and Pearce, 2016).

The role of APV systems in the agricultural sector is not only to ensure more efficient use of agricultural land but also to help producers meet their energy needs and reduce energy costs. Integrating solar panels into agricultural areas can improve the growing conditions of plants, thereby increasing agricultural productivity. Furthermore, through these systems, agricultural enterprises can play a significant role in combating climate change by reducing greenhouse gas emissions and contributing to environmental sustainability. While encouraging the use of renewable energy in the agricultural sector, APV systems also have the potential to create an additional source of income for producers from an economic perspective.

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3.2.2. Application areas of APV systems

Research is currently being conducted on the various application areas of APV systems. These systems can be utilized across different segments of the agricultural sector. They provide economic benefits by increasing energy efficiency in many areas, including animal production -primarily dairy and beef cattle farming- as well as crop production in fields and orchards, and protected cultivation (greenhousing).

One of the most critical aspects of APV systems is the selection of appropriate crops. Shade-tolerant plants are the most suitable candidates for APV systems. Important parameters in crop selection include direct sunlight requirements, soil/preparation needs, water/irrigation requirements, plant height, and potential for evaporation and cooling (Cristiano et al, 2016; Mudau et al., 2017; Chae, et al, 2022). Suitable plants for APV systems include Malabar nut, Aloe Vera, broccoli, spinach, and tomato (Figure 1).

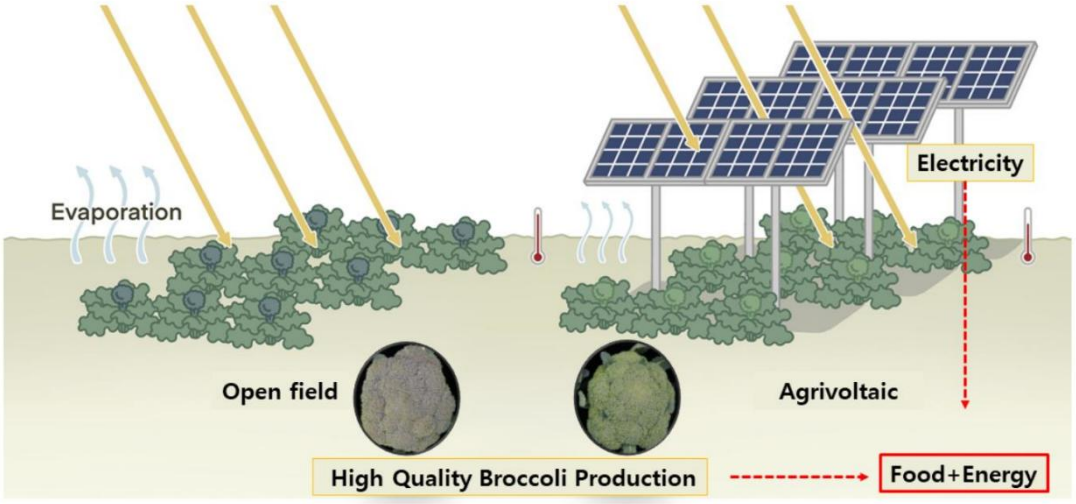

Figure 1. Broccoli Production in an APV System

Source: Chae et al., 2022

Research on the integration of APV systems also includes profitability analyses demonstrating that they can provide economic benefits in terms of both agricultural and electrical energy production. Moreda et al. (2021) analyzed the profitability of a hypothetical APV system established in southwestern Spain. The results indicate that the APV system can provide economic advantages for both agricultural and electrical energy production. Recently, the use of dynamic (mobile) PV panels in greenhouses has also been investigated (Li et al., 2018). The integration of solar panels with agricultural land offers a dual-use structure that optimizes the microclimate required for plant development while simultaneously enabling energy production (Figure 2).

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Figure 2. UMass South Deerfield APV System

Source: Doubleday et al., 2025

In recent years, the integration of the APV concept has begun to be evaluated as a strategic solution in specific agricultural systems such as viticulture and intensive fruit production. The presence of existing support structures (trellis systems, anti-hail nets, etc.) in these production systems provides a synergistic benefit by reducing infrastructure costs for the installation of APV units. APV systems can increase land-use efficiency by over 60%. Instead of performing 100% wheat production and 100% electricity production on separate 1-hectare areas, hybrid use of the same land makes it possible to obtain the total yield of 2 hectares from a much smaller area-with 80% wheat and 80% energy output. This situation not only maximizes the income per unit area, especially in high-value-added orchards, but also protects the plants from environmental stress factors such as excessive solar radiation (Figure 3).

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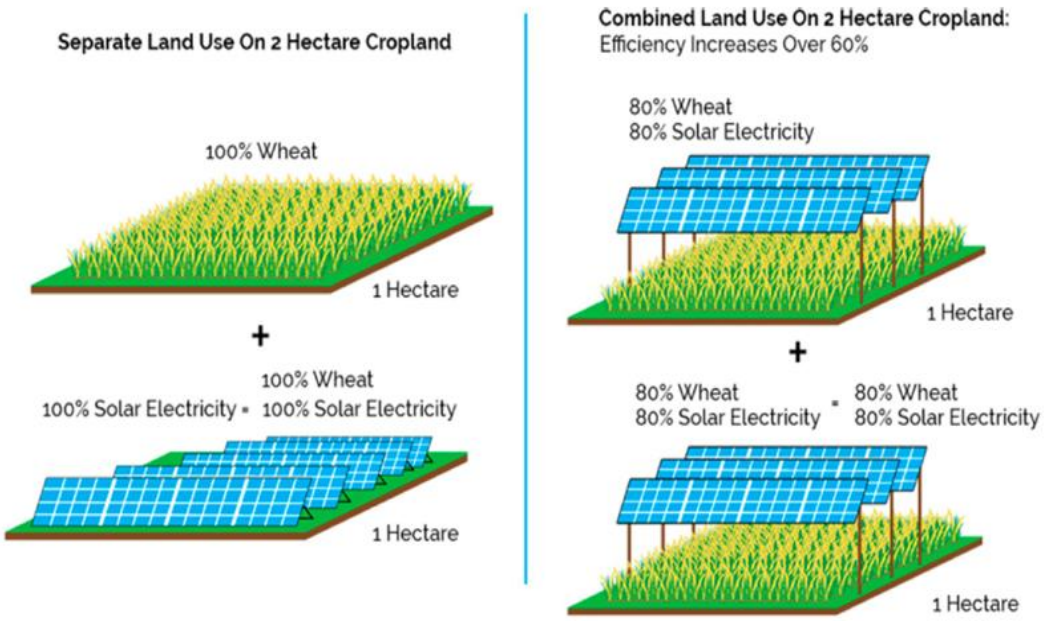

Figure 3. Agrivoltaic Land-Use Efficiency

Source: Zainol Abidin et al., 2021; Njema et al., 2025

3.2.3. Integration of APV systems into Agricultural Production

The integration of APV systems into agricultural production processes introduces a series of technical requirements to optimize both energy efficiency and agricultural yield. In terms of physical integration, the mounting structure of the PV arrays must be positioned at an appropriate height to allow for the comfortable passage of agricultural machinery (at least 4-5 m is required for large machinery); meanwhile, the footprint of the poles should be kept at a maximum of 2% of the land area. The shading level and continuity within APV systems vary depending on the technical specifications of the solar panels (orientation, tilt angle, density) and geographical location. To adjust the irradiance under the panels to maintain acceptable agricultural yields, the PV array density should be kept lower compared to traditional plants, with a recommended row spacing of approximately 3 m technical solutions include mobile PV panels that change tilt according to the light sensitivity of the plants, as well as semi-transparent and bifacial modules.

The most prominent change in microclimate effects is the reduction in solar radiation, which causes the radiation reaching the plant level to be between 60% and 85% of open-field conditions (Dupraz et al., 2011). The impact of shading on product yield is critical depending on the plant species and the growth stage in which it is applied. For example, while moderate shading (15-40% reduction) barely affects lettuce yield and can even increase the yield of some Mediterranean climate vegetables (tomatoes, sweet peppers), it can lead to yield losses in crops with high light requirements such as corn, rice, and potatoes. Furthermore, APV systems can increase water-use efficiency by reducing evaporation and transpiration through the shading effect of the panels (Marrou et al., 2013); however, challenges such as uneven water distribution and the risk of soil erosion during heavy precipitation may also arise. These risks can be

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managed through technical features such as adjustable tilt angles. Since dust accumulation on the panel surface also reduces electrical performance, the importance of module cleaning increases (Dinesh and Pearce, 2016).

3.2.4. Advantages and disadvantages of APV systems

As an innovative approach that enhances land-use efficiency, APV prevents the total allocation of agricultural land to energy production, thereby optimizing both food and energy yields. These systems contribute significantly to water conservation, particularly in arid and semi-arid climate regions, by reducing evaporation and plant water stress through the partial shading provided by PV panels. Economically, APV applications offer producers the potential to lower energy costs, meet their own energy requirements, and generate additional income by selling surplus electricity to the grid. This situation increases the economic resilience of agricultural enterprises while supporting the fight against climate change by reducing dependence on fossil fuels.

However, there are also challenges in the implementation of APV systems. This integration, which requires a more complex infrastructure compared to traditional solar energy systems, brings high initial installation and maintenance costs. In terms of agricultural constraints, the shading from panels can cause yield loss by reducing the photosynthetic rate in certain plant species with high sunlight requirements, while the installation layout can create difficulties in using large-scale agricultural machinery, thus requiring additional labor. Furthermore, technical issues such as the necessity of positioning panels at appropriate angles, the requirement for site-specific designs for each region, and the accumulation of dust or dirt on the panel surfaces can hinder the efficient operation of the system. Given these technical and economic challenges, more research and development work addressing these constraints is needed for the widespread application of APV systems.

In European countries, certain measures have been taken to promote the expansion of these systems. As of 2023, France has over 2 GW of agrivoltaic application capacity, and legal regulations prioritize APV installations for agricultural purposes. In Italy, a special incentive program worth 1.1 billion Euros was launched in 2024 for the installation of APV systems on agricultural land. In Germany, the performance of integrated systems in livestock and vegetable production areas is being measured through federally supported pilot projects. In the Netherlands, innovative solutions such as vertical applications maintain the maneuverability of agricultural machinery while supporting energy production (Anonymous, 2025).

3.2.5. Efficiency and performance of APV systems

APV systems, particularly in arid climates, increase water-use efficiency and preserve soil moisture by reducing evaporation through the shading effect of the panels (Harinarayana and Vasavi, 2014; Hassanpour Adeh et al., 2018). These systems create an additional source of income for producers through electricity generation on agricultural lands (Dinesh and Pearce, 2016; Malu et al., 2017) and contribute to electrification by providing off-grid energy solutions in rural areas. The fundamental performance of APV systems is measured using the Land Equivalent Ratio (LER) method (Mead and Willey, 1980; Dupraz et al., 2011), and simulations indicate that total land productivity can be increased by up to 70%. Furthermore, modeling studies have demonstrated that APV systems can double the land-based renewable energy

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efficiency compared to traditional methods (Amaducci et al., 2018). While technical advancements maximize APV system yield, dynamic (sun-tracking) PV modules and mounting structures with heights increased to 4–5 meters are utilized to support crop production.

On a global scale, small-scale systems have been established in Japan since 2004 under the name "Solar sharing" (Movellan, 2013), while in Europe, large-capacity commercial and pilot research facilities have been implemented in Italy, France, and Germany. In these facilities, different panel densities have been tested, and the performance of various crops such as lettuce, cucumber, wheat, and crop rotations has been examined. The "BayWa r.e." project in the Netherlands, focused on raspberry production, is considered one of the largest agrivoltaic projects in Europe. In France, there is a pilot project where over 5,000 solar panels are installed over an agricultural enterprise, with a capacity to produce 2.5 MW at peak times. In Greece, aromatic plants and flowers are grown using APV systems. In Spain, it has been determined that plants such as artichokes and broccoli continue their development without issues under solar panels. In Belgium, pear and sugar beet production is carried out under solar panels (Enerjisa Üretim, 2024).

3.2.6. Evaluation of APV systems for Türkiye

The integration of renewable energy sources into the agricultural sector is gaining momentum in Türkiye. The 2024-2028 Strategic Plan of the Ministry of Agriculture and Forestry (MAF) emphasizes that the idle capacity of renewable energy should be utilized to ensure sustainability in agriculture, reduce production costs, and decrease foreign dependency. However, the plan also highlights the risk that using agricultural and pasture lands for solar energy production could pose potential threats to agricultural output (MAF, 2024). In this context, it has become crucial to carefully examine APV systems, which enable both agricultural and energy production on the same land unit.

Research indicates that a large part of Türkiye is geographically suitable for APV systems (Coşgun, 2021). Studies conducted in the provinces of Burdur and Muş have revealed that while APV systems provide direct benefits to food and energy production, they also indirectly improve water use and reduce air pollution (Kırbaş, 2023; Özer, 2024). Additionally, Enerjisa Üretim has implemented an APV system in Istanbul Komşuköy with a capacity of 20 kW and a storage capacity of 24 kWh (Enerjisa Üretim, 2024; Anadolu Agency, 2024). This system stands out as a pioneering agrivoltaic application area in Türkiye, designed with a fixed bifacial panel system (Figure 4).

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Figure 4. Komşuköy APV System

Source: Şentürk et al., 2024

Türkiye's first APV Research Project is being conducted within the scope of the Livinglab initiative launched by the Middle East Technical University (METU) Solar Energy Research and Application Center (GÜNAM). The Ayaş APV project, carried out jointly by METU-GÜNAM, the Ayaş District Directorate of Agriculture and Forestry, and a local producer in the Ayaş district of Ankara, is equipped with a 122 kWp (Kilowatt-peak) capacity and a single-axis solar tracking system (Anonymous, 2023). This system provides a suitable working area for agricultural vehicles, and in its first year of trial, products such as tomatoes, peppers, and cucumbers were monitored in accordance with the local cropping pattern. Within the scope of the project, environmental parameters (irrigation, soil moisture, and temperature) are measured, and detailed analyses, including agricultural productivity, energy efficiency, and income-expenditure calculations, are maintained over a four-year period (Figure 5).

Figure 5. Ayaş-Ankara APV System

Source: Anadolu Agency, 2023

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APV systems are technically highly suitable for Türkiye due to its high solar radiation potential. Partial shading provided by the panels could enhance crop yield and water savings in regions with high water stress (Central Anatolia, Southeast). Its ability to reduce irrigation requirements could offer significant contributions to combating drought. In addition to providing extra income for producers, it allows for the co-development of energy and agriculture. Furthermore, it can contribute to the reduction of carbon emissions. However, the high cost of installation remains a significant factor. In Türkiye, legislation and land-use regulations regarding this issue are not yet sufficiently clear. The term "APV" is not an officially defined application in current legal regulations. At present, the installation of solar energy systems on agricultural land is evaluated as "non-agricultural use." Due to the narrowing of application areas, investors mostly turn to marginal and low-yield lands.

On the other hand, the fact that these systems are not suitable for every crop may also affect producers. Producers may require technical knowledge and training, and crop-panel designs must be well-planned for system success. In Türkiye, agricultural and energy incentives are not structured together. To promote the expansion of APV systems, state-supported investment grants could be provided. Integrating energy and agricultural incentives, along with providing tax advantages and financial support, would also make a significant contribution. Education and consultancy services could be expanded. For producers to adopt these systems, they must be supported both technically and financially.

4. DISCUSSION AND CONCLUSION

Although APV systems are in the early stages of their development, they offer significant technical improvements and new application opportunities. Technical innovations include dynamic PV modules (Valle et al., 2017) that optimize the irradiance reaching the vegetation to increase both electricity and biomass yield, wavelength-selective PV modules (Loik et al., 2017), and the integration of wind turbines. Application areas cover a wide range, including the use of generated electricity for agricultural operations (processing, cooling), vehicle electrification, and providing rural electrification in developing countries (Malu et al., 2017). Furthermore, the integration of APV systems with water pumping systems (Burney et al., 2010) holds the potential to improve water supply in arid regions, enhance pasture productivity, and mitigate desertification (Campana et al., 2016). APV systems are particularly beneficial in sectors where supporting structures are already utilized, such as hops, greenhouse cultivation, viticulture, and fruit production (Cossu et al., 2014). In sub-sectors like viticulture and orcharding, APV systems not only provide water savings but also reduce crop losses by offering protection against extreme weather conditions, thereby significantly increasing farm income (Malu et al., 2017). Considering the impact of climate change on reducing agricultural land (Hannah et al., 2013), APV systems are evaluated as a critical technology that alleviates the ethical conflict in land use by combining agriculture and energy production.

In conclusion, APV systems offer a vital solution for achieving sustainable development goals by integrating agricultural and energy production. Advantages such as the cost-effectiveness of solar energy and its non-polluting nature accelerate the adoption of APV systems in the agricultural sector. By enabling both energy production and agricultural activities on the same

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land, APV systems provide the potential to establish a nexus between energy and food production. The expansion of these systems will enhance the success of sustainable agricultural practices and renewable energy strategies. However, further research addressing the effects of APV systems on crop yields and quality is required. In the future, modeling techniques should be employed to transform field experiment results into universal models. These models must be adapted to specific climatic conditions and technical applications of APV systems. By addressing major social and environmental challenges such as global energy demand, food security, climate change, and land use, APV systems are candidates to become a key component of future agricultural systems. For Türkiye, it is a powerful model that can provide solutions to drought, energy dependency, and rural income problems. However, for its widespread adoption, pilot projects, support mechanisms, and a clear legal framework are essential.

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SOME PRACTICES AND THEIR IMPACT ON TURKISH FOREST AREA

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ABSTRACT

According to the latest Turkish forestry inventory, Türkiye has 23.4 million hectares' forest area of which 41% is unproductive (9.6 million ha), while they changed annual by forestry practices such as afforestation, rehabilitation, private plantation and natural regeneration, or damages such as forest fire, erosion, and insect damages. Total forest area of Türkiye increased from 20.2 million ha to 23.4 million ha opposite to decreasing of unproductive forest from 56% to 41% by these practices between 1973 and 2024. For instance, 17759 ha forest area was afforested by seeding or planting in 2024. 84 523 823 seedlings and 52.8 tones seeds were produced in 2024. Afforestation (i.e., 30183 ha in 2022 and 15 488 ha in 2023), seedling and seed production of some natural and exotic tree species (i.e., Brutian pine- *Pinus brutia* Ten., Black pine- *Pinus nigra* Arnold., Taurus cedar- *Cedrus libani* A. Rich., Maritime pine- *Pinus pinaster* Ait.) and their effects on forest area were examined and discussed based on some years for future practices in this paper.

Key Words: Afforestation, forestry, pine, seed, seedling.

1. INTRODUCTION

Forest area and its productivity can change with forestry practices (i.e., afforestation, rehabilitation, plantation, regeneration, wood harvest) or damages (i.e., forest fire, erosion, and insect damages) and also with other practices [1]. For instance, total forest area of Türkiye increased from 20.2 million ha to 23.4 million ha between years 1973 and 2024 (Table 1) [2]. Besides, ratio of productive area increased from 41% to 56% for the years (Table 1, Figure 1) [2].

Table 1. Turkish forest areas for some years

	Productive		Unproductive		Total
Years	**Area**	**%**	**Area**	**%**	**Area**
1973	8.9	44	11.3	56	20.2
2020	13.2	58	9.6	42	22.9
2021	13.5	58	9.6	42	23.1
2022	13.7	57	9.5	38	23.2
2023	13.7	59	9.6	41	23.3
2024	13.8	59	9.6	41	23.4

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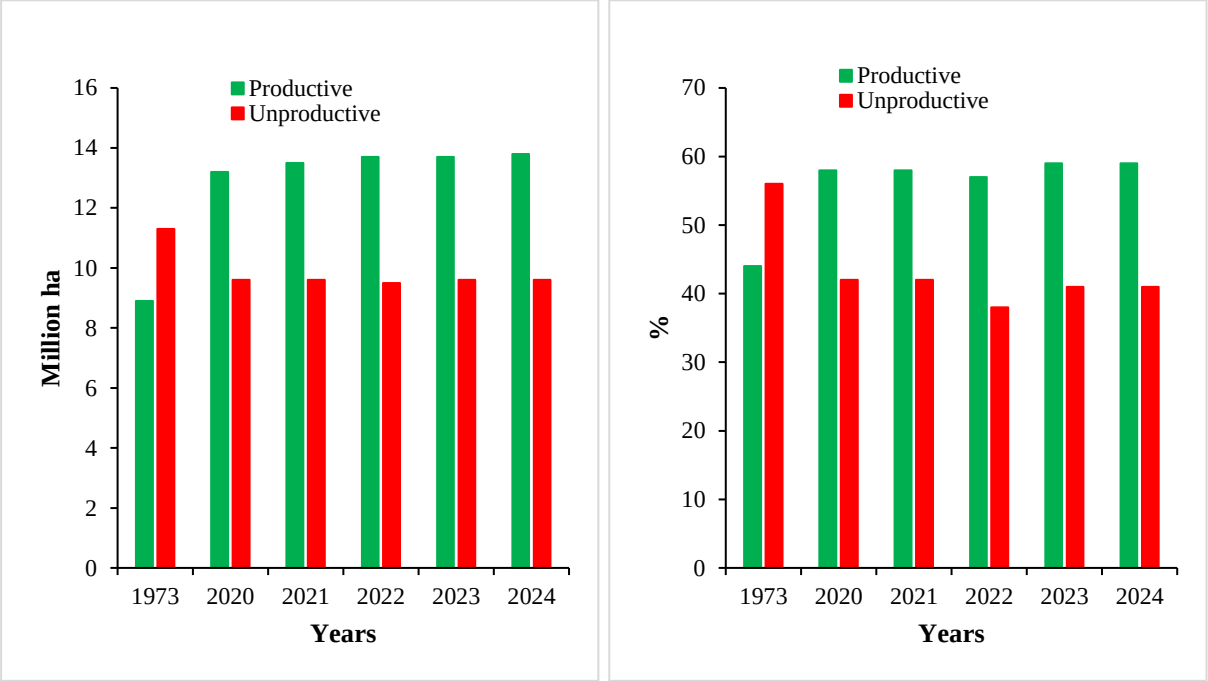

Figure 1. Forest area and its productivity of Türkiye for some years

Afforestation, seedling and seed production of some natural Brutian pine (*Pinus brutia* Ten.), Black pine (*Pinus nigra* Arnold.), Scots pine (*Pinus sylvestris* L.), Taurus cedar (*Cedrus libani* A. Rich.), Oriental beech (*Fagus sylvatica* Lipsky.), Oriental spruce (*Picea orientalis* (L.) Link.), Walnut (*Juglans* ssp.) and Cypress (*Cupressus* ssp.) and exotic tree species (Maritime pine (*Pinus pinaster* Ait.) and Black locust (*Robinia pseudoacacia* L.) their effects on forest area were examined based on some years to discuss for future practices in this paper.

2. MATERIAL AND METHOD

Inventorial data of afforestation, seedling and seed production was obtained from website of General Directorate of Forestry of Turkey [2], published annual.

3. RESULTS AND DISCUSSION

3.1. Reforestation and afforestation

Afforestation and reforestation (Figure 2) by seeding or planting both refer to establishment of trees on non-treed land. Reforestation refers to establishment of forest on land that had recent tree cover, whereas afforestation refers to land that has been without forest for much longer [3]. According to the latest Turkish forestry inventory [2], areal reforestation and afforestation practices were given in Table 2 to discusses annual changes. As seen from Table 2, annual averages of the practices were about 34500 ha. The first inventorial afforestation practice was 264 ha in 2018 [2], while it has continued inventorially after the year (Table 2). Many biotic and abiotic factors could impact in these practices and their amount such as seed and seedling production, forest fire, unexpected natural damages.

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Table 2. Areal reforestation and afforestation practices (ha) in Türkiye for some years

Years	Reforestation	Afforestation	Total
1946-1991	-	-	1 550 511
2020	28 523	109	28 632
2021	35 372	1 514	36 887
2022	29 631	552	30 183
2023	15 195	293	15 488
2024	17 326	433	17 759

Figure 2. Afforestation and reforestation practices in *Pinus nigra* and *P. sylvestris*

3.2. Seed and seedling productions

Seed and seedling productions were the main materials of afforestation and reforestation practices by seeding or planting in conversion of unproductive forest to productive forest. Seed productions of some forest tree species were given in Table 3 and Figure 3 [2]. It could be said that seed (Table 3, Figure 3) and seedling productions of the species related to their amount of their natural distributions. However, weight of seed productions could not reflect their practices because of size and weight variation among the species.

Table 3. Seed productions (kg) for some species and years

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Türkiye/ Species	Years 2020	2021	2022	2023	2024	Total
Türkiye	**143 800**	**146 500**	**116 750**	**118 000**	**116 000**	**524 300**
P. brutia	9 542	11 199	10 843	7 871	11 736	51 191
P. nigra	1 428	1 455	534	5 535	5 630	14 582
C. libani	9 062	6 598	7 851	12 347	8 652	44 510
P. sylvestris	420	352	113	924	992	2 801
*R. pseudoacacia**	1 388	2 905	2 421	1 561	1 305	9 580
Cupressus ssp	742	460	556	1 530	1 084	4 372
*P. pinaster**	1 769	1 006	490	420	470	4 155
F. orientalis	5 180	4 486	5 245	3 160	4 135	22 206
P. orientalis	2	197	75	-	310	584
Juglans ssp.	20 413	20 703	23 742	24 694	18 446	107 998
Total	49 946	49 361	51 870	58 042	52 760	261 979

*; exotic species

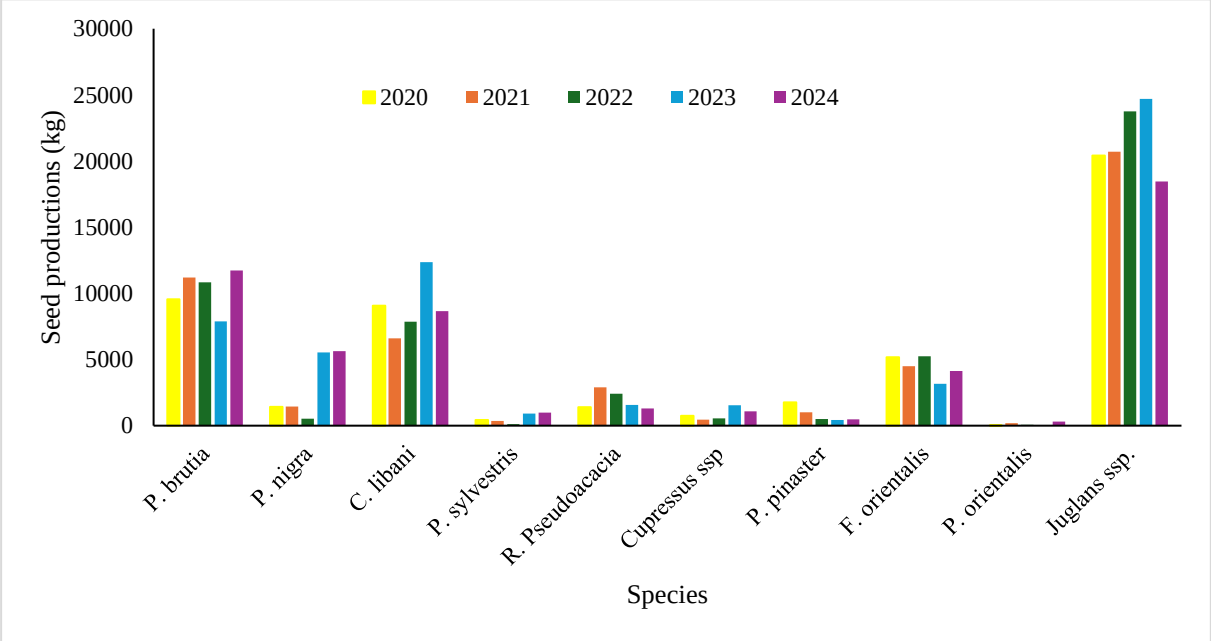

Figure 3. Seed productions for some species and years

Number of both bare-root and container seedlings (Figure 4) produced from the harvested seeds generally were given in Table 4 and Figure 5 [2]. Seedling type and age could impact on number of seedling productions.

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Figure 4. Container and bare-root seedling productions in *Cupressus* and *P. brutia*.

Table 4. Seedling productions for some species and years

Türkiye/			**Years**			
Species	**2020**	**2021**	**2022**	**2023**	**2024**	**Total**
Türkiye	**273 533 826**	**274 929 790**	**260 000 000**	**261 295 000**	**131 675 000**	**1201 433 616**
P. brutia	69 714 397	53 350 545	53 361 445	50 404 772	48 734 295	275 565 454
P. nigra	37 992 812	43 256 631	43 754 476	36 833 132	16 039 800	177 876 851
C. libani	26 848 957	30 475 755	28 066 309	47 722 135	9 619 569	142 732 725
P. sylvestris	22 573 380	25 649 510	23 886 926	21 180 524	5 991 020	99 281 360
*R. pseudoacacia**	10 110 018	11 718 248	11 798 225	10 196 203	3 056 065	46 878 759
Cupressus ssp	6 459 691	7 512 651	9 285 469	10 584 870	8 867 006	42 709 687
*P. pinaster**	6 413 719	6 079 056	7 832 090	4 821 073	3 982 832	29 128 770
F. orientalis	3 049 465	5 070 851	4 646 580	5 685 214	1 605 786	20 057 896
P. orientalis	3 541 024	4 653 732	4 088 355	4 338 628	1 550 750	18 172 489
Juglans ssp.	5 592 536	4 122 974	2 965 573	2 806 023	1 116 500	16 603 606
Total	192 295 999	191 889 953	189 685 448	194 572 574	84 523 823	869 007 597

*; exotic species

Seed and seedling productions (Tables 3 and 4, Figures 3 and 5) could not be well accordance each other because of 1000 seed weight and seedling types of the species. So, seedling production could be better monitor of afforestation and reforestation practices.

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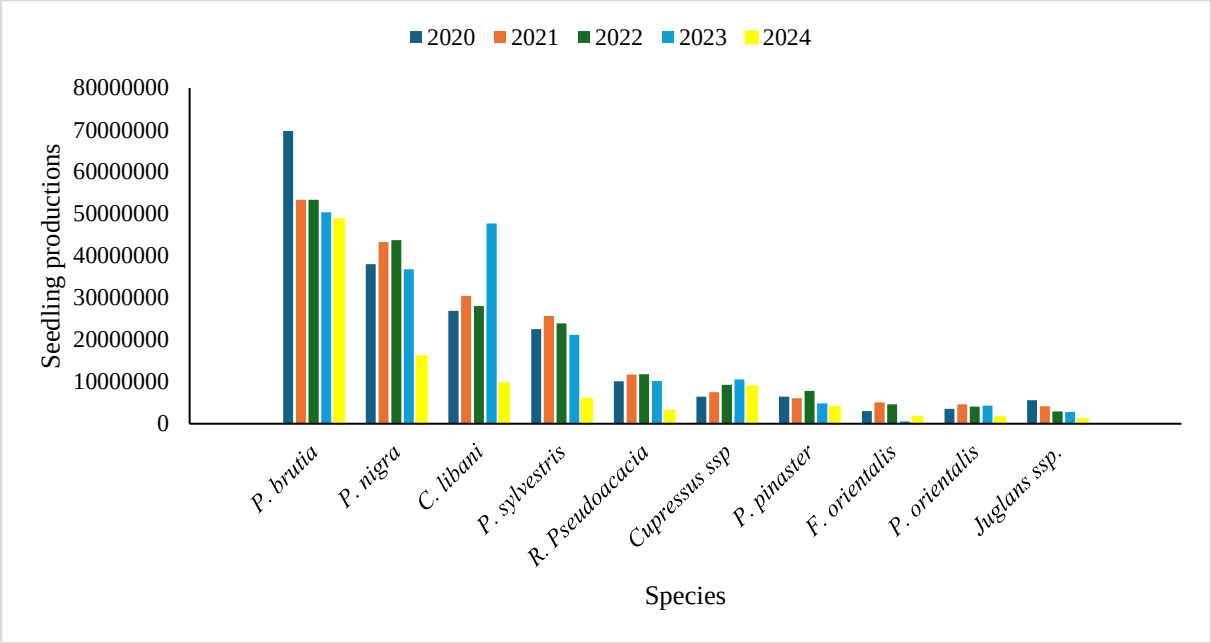

Figure 5. Seedling productions for some species and years

4. CONCLUSIONS

Vegetative seedling propagation could be also considered especially for extreme areas. Private afforestation could be much encouraged.

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JUNIPERS (*JUNIPERUS* SSP.) OF TÜRKİYE AND THEIR SILVICULTURAL IMPORTANCE IN TURKISH FORESTRY

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ABSTRACT

Junipers (*Juniperus* spp.) as tree, small tree or shrubs, evergreen woody plants belonging to Cupressaceae family are important in wood and non-wood forest products, and also landscape practices. Number of Junipers species was 53 or 67 according to literature survey in whole the world. They to be represented by 8 natural species belong to Juniperus (*Juniperus oxycedrus* L., *J. communis* L. and *J. macrocarpa* Sibth. & Sm.), Caryocedrus (*Juniperus drupacea* L.) and Sabina (*Juniperus excelsa* M. Bieb., *J. foetidissima* Willd., *J. phoenicea* L. and *J. sabina* L.) sections in Turkish forestry at different edaphic, climatic and environmental conditions. Crimean juniper (*Juniperus excelsa* M. Bieb.) has the largest natural area in Turkish junipers. They grow at 1.59 million ha which of 70% (1.12 million ha) is unproductive in total 23.4 million ha Turkish forest area which of 9.5 million ha (41%) is unproductive. The Junipers are used widely in afforestation and rehabilitation practices in Türkiye for conversion of unproductive forest to productive forest. For instance, 25841 kg seeds were harvested from 6 seed stands at 1357.7 ha in junipers and about 123 million seedlings inventoried in other coniferous forest tree seedlings were produced in last decade according to the last forestry inventory. Importance of silvicultural practices were examined to discuss based on forestry practices of Junipers in this study.

Key Words: Afforestation, rehabilitation, seed, landscape.

4. INTRODUCTION

Junipers (*Juniperus* spp.) taxa as tree, small tree or shrubs, evergreen woody plants (Figure 1) have 1.59 million ha natural distribution which of 70% (1.12 million ha) is unproductive in total 23.36 million ha Turkish forest area which of 9.65 million ha is unproductive [1]. Junipers (*Juniperus* spp.) belonging to Cupressaceae family which of dioecious or monoecious [2] are important in wood and non-wood forest products used in various industries [3, 4, 5], and also landscape practices by long lifespan/rotation age. Number of Junipers species was 53 [6] or 67 [7] according to literature survey in whole the world. They were grouped to sections by berry and leaves characteristics. Türkiye has 8 natural species [8] belong to Juniperus (prickly juniper- *Juniperus oxycedrus* L., Common juniper- *J. communis* L. and Maritime juniper- *J. macrocarpa* Sibth. & Sm.), Caryocedrus (Syrian juniper- *Juniperus drupacea* L.) and Sabina (Crimean juniper- *Juniperus excelsa* M. Bieb., Stinking juniper- *J.*

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foetidissima Wild., Phoenician juniper- *J. phoenicea* L. and Savin juniper- *J. sabina* L.) sections in Turkish forestry at different edaphic, climatic and environmental conditions (Figure 2) [6]. *Juniperus excelsa* is a tree, which measures about 20–25 m in height with a pyramidal crown together with *J. foetidissima* which is a tree with a height of 10–20 m [5]. Crimean juniper (*Juniperus excelsa* M. Bieb.) has the largest natural area (82%) in Turkish junipers (Figure 3) [9, 10] mainly karstic and rocky areas as individual tree, group or small stands also native in Albania, Yugoslavia, Greece, Macedonia, Bulgaria, Cyprus, Syria, Lebanon, Azerbaijan, Crimea, Russia between 500 and 2700 m (Figure 3).

Figure 1. Tree, small tree and shrub forms of junipers

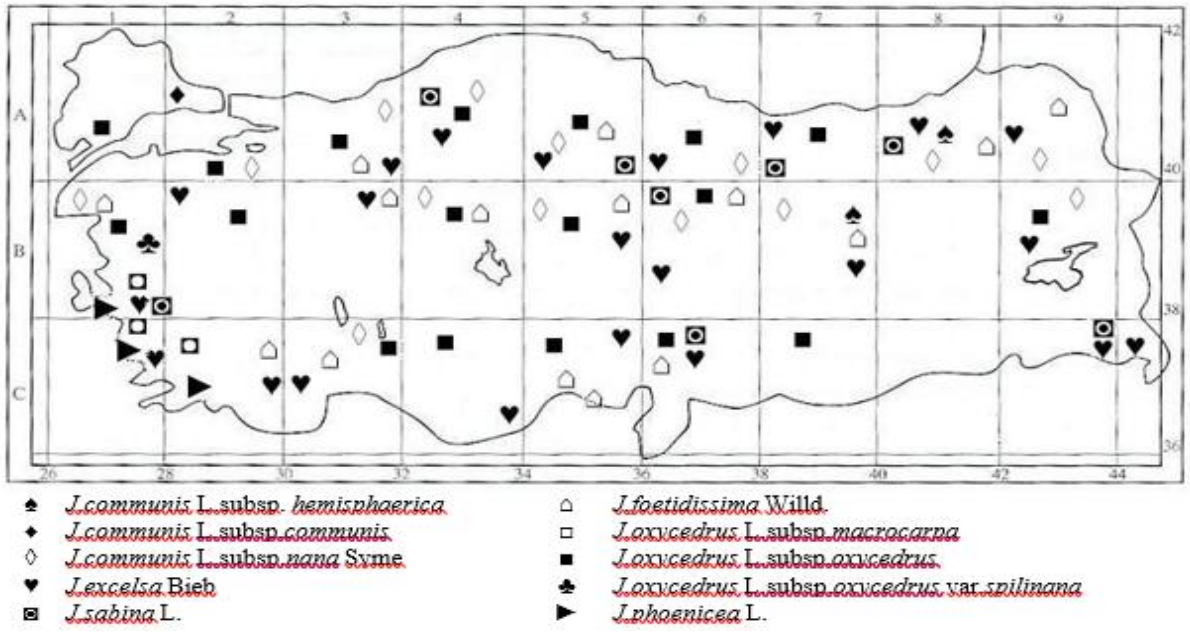

Figure 2. Natural distribution of Turkish junipers

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Figure 3. Natural distribution of Crimean juniper

The Junipers are used widely in afforestation, reforestation and rehabilitation practices in Türkiye for conversion of unproductive forest to productive forest. For instance, 25841 kg seeds were harvested from 6 seed stands at 1357.7 ha in junipers and about 123 million seedlings inventoried in other coniferous forest tree seedlings were produced in last decade according to the last forestry inventory [1,12]. Importance of silvicultural practices were examined to discuss based on forestry practices of Junipers in this paper.

5. MATERIAL AND METHOD

Observation and experience of the author, search of published papers, and also inventorial data from website of General Directorate of Forestry of Turkey [1] was used in this paper.

6. RESULTS AND DISCUSSION

Junipers which have been very well adapted to both hard conditions and dryness [2] grow at different edaphic, climatic and environmental conditions (Figure 4). Wood production was 20761 m^3 for year of 2024 [1]. Juniper taxa have used widely in afforestation, rehabilitation and reforestation practices especially in extreme areas because of these advantages and rich taxa (Figure 5) after solution of germination problems of juniper taxa by Gültekin (2007) [11]. 25841 kg seeds and 123 million seedlings were produced in last decade in the junipers to produce quality seedlings for Turkish forestry practices [1]. For instance, average 1000 seed weight was 17.1 g in Common juniper, while they varied largely among taxa and among provenances within taxa such as ranged from 15.6 g to 19.4 g in the species [11]. There were about 58000 seeds/kg in Common juniper, while they changed according to taxa and provenances [11]. Number of seedlings and weight of seed productions could change for the years and forestry practices, and also good seed year of junipers.

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Figure 4. Common juniper and Black pine in rocky area

Figure 5. Seedlings and mix plantation of Crimean juniper

Junipers especially Crimean juniper (*Juniperus excelsa*) has drought, heat and cold tolerant characteristics. It is getting importance based on climate change and adaptation ability to different ecological conditions of junipers. Bare-root and containerized seedlings used in forestry practices showed large variation for seedling height and root-collar diameter in Crimean juniper, while it had higher quality seedlings for the practices [13,14].

4. CONCLUSIONS

Pure afforestation and reforestation practices should be increased in Junipers based on seed and seedling productions by seeding and seedling.

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ÇANKIRI İLİNDE 2020-2025 YILLARINDA YAPILAN AĞAÇLANDIRMA ÇALIŞMALARININ DEĞERLENDİRİLMESİ

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ÖZET

Ağaçlandırma çalışmaları, bitki örtüsünün tahrip edilmesi sonucu oluşan bozuk alanların yeniden ormana dönüştürülmesi açısından büyük önem taşırlar. Bunun yanı sıra erozyon, iklim değişikliği, küresel ısınma gibi çevre sorunlarının olumsuz etkilerinin azaltmasında da önemli bir rol oynamaktadır. Kurak ve yarı kurak alanlarda ekosistemin daha duyarlı bir yapıya sahip olması nedeniyle bu alanlarda yapılacak ağaçlandırma çalışmalarına daha fazla özen gösterilmesi gerekmektedir. Kurak ve yarı kurak alanlarda toprak derinliği, taşlılık vb. ekolojik koşullara bağlı olarak makineli arazi hazırlığı, uygun ekipman ve deneyimli işçi sağlanması gibi çeşitli güçlüklerle karşılaşılabilmektedir. Bu nedenle kurak ve yarı kurak alanlarda yapılacak ağaçlandırma çalışmaları klasik ağaçlandırmalara göre daha fazla yatırım gerektirmektedir. Ayrıca bu alanlarda ağaçlandırmalarda kaplı/tüplü fidanların dikilmesinin başarı oranını artırdığı bilinmektedir. Bu çalışmada yarı kurak alan özelliğine sahip Çankırı ilinde 2020-2025 yılları arasında yapılmış ağaçlandırma çalışmaları incelenmiştir. İncelemeler sonucu Çankırı'da hem ağaçlandırma hem de erozyon kontrol uygulama projeleri yapıldığı saptanmış, bu çalışmalarda kullanılan fidan türleri ve yaşları, orijinleri ve yaşama yüzdeleri değerlendirilmiştir. Ayrıca ağaçlandırma çalışmalarının 2023-2025 yıllarına ait yaşama yüzdeleri tespit edilmiş, fidan sayım tutanaklarına göre başarı yüzdesinin %86-97 arasında değiştiği saptanmıştır. Ancak erozyon kontrol amaçlı yapılan çalışmalarda öncelik toprağı korumak olduğundan bu çalışmalarda herhangi bir fidan sayımı yapılmadığı görülmüştür.

Anahtar Kelimeler: Ağaçlandırma, Fidan türü, Çankırı, Yaşama yüzdesi.

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EVALUATION OF AFFORESTATION STUDIES CARRIED OUT IN ÇANKIRI PROVINCE BETWEEN 2020-2025

ABSTRACT

Afforestation efforts are of great importance in restoring degraded areas, resulting from the destruction of vegetation, back into forest. Furthermore, they play a significant role in mitigating the negative effects of environmental problems such as erosion, climate change, and global warming. Due to the more sensitive ecosystem structure in arid and semi-arid areas, afforestation efforts in these regions require greater care. In arid and semi-arid areas, various difficulties can be encountered, such as mechanized land preparation, securing appropriate equipment, and providing experienced workers, depending on ecological conditions like soil depth and stoniness. Therefore, afforestation efforts in arid and semi-arid areas require more investment than conventional afforestation methods. Additionally, it is known that planting containerized/potted seedlings increases the success rate in these areas. This study examines afforestation efforts carried out in Çankırı province, a semi-arid area, between 2020 and 2025. The investigations revealed that both afforestation and erosion control projects were carried out in Çankırı, and the types, ages, origins, and survival rates of the seedlings used in these projects were evaluated. Furthermore, the survival rates of the afforestation projects for the years 2023-2025 were determined, and according to the seedling count records, the success rate was found to vary between 86% and 97%. However, it was observed that no seedling counts were conducted in the erosion control projects, as the priority is soil conservation.

Keywords : Afforestation, Seedling type, Çankırı, Survival rate.

1. GİRİŞ

Bitki örtüsünün tahribi sonucunda oluşan bozuk alanların yeniden ormana dönüştürülmesi açısından büyük önem taşıyan ağaçlandırma çalışmaları; erozyon, iklim değişikliği, küresel ısınma, çölleşme gibi çevre sorunlarının neden olduğu olumsuz etkilerin azaltmasında da önemli bir rol oynamaktadır [1, 2].

Ülkemiz Karadeniz kıyı bölgesi hariç kurak ve yarı kurak iklim koşullarının hakim olması nedeniyle hassas bir ekosisteme sahiptir. Ülke genelinde görülen yarıkurak iklim şartları ormancılık faaliyetlerinin önemini belirgin şekilde ortaya koymaktadır. Özellikle İç Anadolu Bölgesi, Doğu Anadolu Bölgesi ve Güneydoğu Anadolu Bölgesi en düşük yağış alan ve kuraklığın daha belirgin hissedildiği alanlar arasında yer almakta olup, bu yörelerde çölleşme tehlikesinden söz edilmektedir [3, 4]. Bununla beraber İç Anadolu'da Tuz Gölü ve çevresi 300 mm'ye yakın yıllık yağışlar ile kurak bölge olma sınırına yakın özellikler gösterir [5].

Dünyanın % 46'sı kurak ve yarı kurak alanlardan oluşmakta olup Türkiye'de ise kurak ve yarıkurak alanların oranı yaklaşık % 65 düzeyindedir [6]. Ayrıca gerekli tedbirler alınmadığı takdirde, bu alanların zaman içerisinde çölleşme riskinin ortaya çıkması kaçınılmazdır. Bu nedenle Türkiye'de özellikle kurak ve yarıkurak alanlarda gerçekleştirilen ağaçlandırma

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çalışmaları, hem mevcut ekosistemlerin ve biyolojik çeşitliliğin korunması hem de bozulan alanların yeniden iyileştirilmesi açısından büyük önem taşımaktadır [2].

Kurak ve yarıkurak alanların ağaçlandırmaları, klasik ağaçlandırma çalışmalarına göre daha fazla deneyim ve teknik bilgi gerektirmekte olup bu alanlarda yapay gençleştirme biçimiyle yeni ormanlar kurulması amaçlanmaktadır [5]. Kurak ve yarıkurak alanlarda ağaçlandırma çalışmalarına başlamadan önce ilk olarak ekolojik koşullara uygun toprağın tespiti ve ıslah çalışmaları yapılması daha sonra da koşullara uygun türlerin belirlenmesi gerekmektedir [5]. Ayrıca kurak ve yarıkurak alanlarda yapılacak ağaçlandırma çalışmalarında arazinin toprak derinliği, taşlılık vb. ekolojik koşullarının uygun hale getirilmesi için makineli arazi hazırlığı, uygun ekipman ve deneyimli işçi sağlanması gibi çeşitli güçlüklerle karşı karşıya kalındığından klasik ağaçlandırma çalışmalarına kıyasla daha yüksek maliyet ve yatırım gerektirmektedir [2,7]. Türkiye'de yarıkurak iklim koşulları, başta Konya, Karaman, Niğde, Kayseri, Aksaray, Kırıkkale, Kırşehir, Ankara, Eskişehir ve Çankırı illerinde yaygın olarak görülmekte, bunun yanı sıra Malatya, Elazığ, Diyarbakır ve Şanlıurfa illerinde de yarıkurak nitelikler taşıyan alanlar bulunmaktadır [8,9].

Bu bildiride, yarı kurak alan özelliğine sahip Çankırı ilinde 2020-2025 yılları arasında yapılmış ağaçlandırma çalışmaları incelenmiştir. İncelemeler sonucu Çankırı'da hem ağaçlandırma hem de erozyon kontrol uygulama projeleri yapıldığı saptanmış, bu çalışmalarda kullanılan fidan türleri ve yaşları, orijinleri ve yaşama yüzdeleri değerlendirilmiştir.

2. MATERYAL VE YÖNTEM

Bu çalışmada yarı kurak alan özelliğine sahip Çankırı ilinde 2020-2025 yılları arasında yapılmış ağaçlandırma çalışmaları incelenmiştir. İncelemeler sonucu Çankırı'da hem ağaçlandırma projeleri hem de erozyon kontrol uygulama projeleri yapıldığı saptanmıştır.

2.1. Araştırma Alanlarının Tanıtımı

2.1.1 Ağaçlandırma alanları

Elmacı ağaçlandırma alanı: Alan, Ankara Orman Bölge Müdürlüğü, Çankırı Orman İşletme Müdürlüğü, Eldivan Orman İşletme Şefliği sınırları içinde, 44°80'47"-54°75'50" Kuzey enlemleri 44°80'24"-54°82'46" Doğu boylamları arasında, 1/25.000 ölçekli topoğrafik haritada Çankırı H31 a1 paftasında yer almaktadır. Amenajman planının 106, 121, 124 No'lu bölmelerinde bulunan alan toplam 122,75 ha büyüklüğündedir. Erinç yağış miktarı indisine göre araştırma alanı yarı kurak iklim tipinde olup step vejetasyon tipine sahiptir. Alanda OT-E, BÇk-E, OT ve OT-E-4 meşcere tipleri yaygın olup karaçam, alıç, kuşburnu, ahlat ve meşe türleri bulunmaktadır. Çalışma kapsamında 5,40 ha büyüklüğündeki mevcut vejetasyon alanı korunmuştur. Araştırma alanı doğu bakıda, ortalama yükseltisi 1025 m'dir. Alan kumtaşı ve çamurtaşı anakaya üzerinde gelişmiş olup topraklar killi balçık tekstüründedir. Toprak, yüksek kireç içeriğine (%5,22 - 45,73) sahip ve bazik karakterli (ortalama pH 8,31), organik madde

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miktarı %0,74-2,69 arasında değişmekte, tuzluluk değeri ise 0,10-0,14 mS/cm aralığında olup tuzsuz sınıfta yer almaktadır [10].

Olguntepe ağaçlandırma alanı: Ankara Orman Bölge Müdürlüğü'ne bağlı Çankırı Orman İşletme Müdürlüğü, Şabanözü Orman İşletme Şefliği sınırları içerisinde yer almakta olup, amenajman planında 68, 69 ve 352 numaralı bölmeleri kapsamaktadır. Ayrıca 1/25.000 ölçekli topoğrafik haritalara göre Çankırı G30 d4 paftasında bulunur ve çalışma kapsamında değerlendirilen alan 176,78 ha büyüklüğündedir. Erinç yağış miktarı indisine göre araştırma alanı yarı kurak iklim tipinde olup step vejetasyon tipine sahiptir ve ortalama yükseltisi 1.373 m'dir. Çalışma alanında mevcut vejetasyon, boşluklu (bozuk) ardıç ve karaçam ile otsu türlerden oluşmakta olup, bu alanlar ağaçlandırma açısından potansiyel nitelik taşımaktadır. Topraklar andezit anakaya üzerinde gelişmiş olup balçık ve killi balçık tekstürlüdür; genel olarak orta ve hafif bünyeli yapı göstermektedir. Toprak reaksiyonu pH 6,79-7,61 arasında değişmekte, kireç içeriği oldukça düşük düzeyde (%0,02-0,04) bulunmakta ve organik madde miktarı %0,38-2,79 aralığında olduğu belirlenmiştir [11].

Şabanözü ağaçlandırma alanı: Ankara Orman Bölge Müdürlüğü'ne bağlı Çankırı Orman İşletme Müdürlüğü, Şabanözü Orman İşletme Şefliği sınırlarında yer alan 365 numaralı bölmede bulunan alan BMt ve OT-E-4 meşcere tipine sahiptir. 1/25.000 ölçekli topoğrafik haritalara göre Çankırı G30-C4 ve H30-B1 paftalarında bulunur. Çalışma alanı toplam 98,89 ha büyüklüğündedir. Erinç yağış miktarı indisine göre araştırma alanı yarı kurak iklim tipinde olup step vejetasyon tipine sahiptir ve ortalama yükseltisi 1.100 m'dir. Alanda kalker anakaya hâkim, kumlu killi ve killi topraklar yaygındır; toprak reaksiyonu pH 7,04-8,23 arasında ve kireç içeriği %0,06-13,49 aralığındadır [12].

Sarıtarla - Yukarıyanlar ağaçlandırma alanı: Ankara Orman Bölge Müdürlüğü'ne bağlı Çankırı Orman İşletme Müdürlüğü Çankırı Orman İşletme Şefliği sınırları içerisindedir. Amenajman planında 202, 204, 272 ve 302 numaralı bölmeleri ve 1/25.000 ölçekli topografik haritada G30-C3 ile G31-D4 paftalarını kapsamaktadır. Ortalama yükseltisi 1.050 m olan çalışma alanı 150,36 ha büyüklüğündedir. Erinç yağış miktarı indisine göre araştırma alanı yarı kurak iklim tipinde olup step vejetasyon tipine sahiptir. Çalışma alanında anakaya kalker ve andezitten oluşmaktadır. Toprak analizleri sahada kumlu killi balçık tekstürünün baskın olduğunu göstermekte; toprak reaksiyonu pH 6,89-8,21 aralığında değişmekte, kireç içeriği %1,12-34,39 arasında olup profil derinliğiyle artış göstermekte ve organik madde miktarı %0,58-0,99 düzeyindedir. Topraklar organik madde bakımından çok az sınıfında yer almaktadır [13].

2.1.2 Erozyon kontrol uygulama alanları

İnandık erozyon kontrolü uygulama alanı: Ankara Orman Bölge Müdürlüğü, Çankırı Orman İşletme Müdürlüğü, Merkez Orman İşletme Şefliği sınırlarında, 54°98'19"- 44°70'60" Kuzey enlemleri, 54°97'07"-44°68'40" Doğu boylamları arasında, 1/25.000 ölçekli topoğrafik haritada Çankırı H31 A1 ve H31 A2 paftalarında yer almaktadır. Amenajman planının 404 No 'lu bölmesinde bulunan alan toplam 353,86 ha büyüklüğündedir. Erinç yağış miktarı indisine

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göre araştırma alanı yarı kurak iklim tipinde olup step vejetasyon tipine sahiptir. Alan OT-Z-1 meşcere tipindedir. Karaçam, alıç, kuşburnu ve meşe türleri ile karaçalı, patlangaç, geven ve çalı formunda otsu türler bulunmaktadır. Araştırma alanının; ortalama yükseltisi 1100 m, kuzeybatı bakısı hakimdir. Alan kalker anakayası üzerinde gelişmiş olup topraklar kumlu-killi balçık tekstüründedir. Toprak, orta kireç içeriğine (%3,67-40,78) sahip ve hafif alkalin karakterli (pH 7,86-7,81), organik madde miktarı %0,03-1,32 arasında değişmektedir [14].

Yukarıpelitözü erozyon kontrolü uygulama alanı: Ankara Orman Bölge Müdürlüğü'ne bağlı Çankırı Orman İşletme Müdürlüğü Çankırı Orman İşletme Şefliği sınırlarında; amenajman planının 303 numaralı bölmesinde yer almakta olup meşcere tipi OT-E-26, Z-42 ve Z-44, toplam 137,36 ha büyüklüğündedir. Alanın ortalama yükseltisi 753 m, genel bakısı kuzey ve kuzeydoğudur. Erinç yağış miktarı indisine göre araştırma alanı yarı kurak iklim tipinde olup step vejetasyon tipine sahiptir. Çalışma alanında anakaya kalker olup topraklar %2,88-27,16 arasında değişen çok kireçli, bazik karakterli (pH 7,74-8,45), %0,10-0,98 düzeyinde oldukça düşük organik madde miktarına sahiptir. Tuzluluk ise 0,11-2,33 mS/cm aralığında olduğundan tuzsuz sınıfta yer almaktadır [15].

Gölezkayı-Alva erozyon kontrolü uygulama alanı: Ankara Orman Bölge Müdürlüğü'ne bağlı Çankırı Orman İşletme Müdürlüğü Çankırı Orman İşletme Şefliği sınırlarında; amenajman planının 303 numaralı bölmesinde yer almakta olup 1/25.000 ölçekli topografik haritada G31-D4 ve H31-A1 paftaları arasında toplam 173,38 ha büyüklüğündedir. Alanın ortalama yükseltisi 753 m, genel bakısı kuzey ve kuzeydoğudur. Erinç yağış miktarı indisine göre araştırma alanı yarı kurak iklim tipinde olup step vejetasyon tipine sahiptir. Ortalama yükseltisi 762 m, genel bakısı kuzeydoğudur. Çalışma alanında anakaya kalker olup topraklar %10,13-17,36 arasında değişen orta ile fazla kireçli sınıfında, hafif alkali karakterli (pH 7,70-7,89), organik madde miktarı %0,84-1,34 düzeyinde ve az ve çok az sınıfındadır [16].

2.2. Yöntem

Bu çalışma kapsamında, Çankırı ilinde yapılan ağaçlandırma çalışmaları incelenmiş ve ağaçlandırma alanları ekolojik koşullara uygun tür ve orijin seçimi, toprak işleme yöntemleri, kullanılan fidan türleri ve yaşları, dikilen fidan adetleri ve fidanların yaşama yüzdeleri yönünden değerlendirilmiştir.

3. BULGULAR

Çalışma kapsamında 4 adet ağaçlandırma ve 3 adet erozyon kontrol uygulama projesi olmak üzere toplam 7 adet ağaçlandırma çalışması ele alınmıştır.

Elmacı Ağaçlandırma Sahası

Ağaçlandırma alanında diri örtü temizliği planlanmamış olup mevcut vejetasyon korunarak alan doğal yapısıyla muhafaza edilmiştir. Toprak işleme çalışmaları kapsamında 25,36 ha

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alanda ikili riper ile alt toprak işlemesi, aynı sahada toplam 55,792 km üst toprak işlemesi yapılmıştır. Ayrıca 83,86 ha alanda ekskavatörle toplam 100,632 km uzunluğunda gradoni tipi teras tesis edilmiştir. Teraslar 60-80 cm derinlikte, 120-150 cm genişlikte ve içe doğru %20-40 eğimli olacak şekilde oluşturulmuştur [10].

2021 yılında tesis edilen alanda dikimlerde; Kızılcahamam orijinli 4.000 adet karaçam, Mut orijinli 4.000 adet sedir, Çankırı orijinli 7.500'er adet ahlat ve ceviz ile Malatya orijinli 7.000 adet zerdali kullanılmıştır. 2023 yılında %81,14 oranında olan fidan yaşama yüzdeleri 2024'te %92,73'e ve 2025'te %95,26'ya yükselmiştir [10]. Buna göre ağaçlandırma çalışmalarındaki fidan tutma başarısının, dikim sonrası gerçekleştirilen ot alma, çapa, tamamlama dikimi ve teras onarımı gibi bakım uygulamalarının zamanında ve yeterli düzeyde yapılmasına bağlı olarak bu oranlara ulaştığı belirlenmiştir.

Olguntepe Ağaçlandırma Sahası

Bu alanda, vejetasyon örtüsünün boşluklu (bozuk) Ardıç ve Karaçam'dan oluştuğu ayrıca otsu türlerin bulunduğu ve diri örtü temizliği yapılmadığı belirtilmiştir. Toprak işleme çalışmaları kapsamında 67,22 ha alanda üçlü riper ile alt toprak işlemesi, aynı sahada gradoni şeklinde üst toprak işlemesi yapılmıştır. Ayrıca 3,63 ha'da ekskavatör ile çukur şeklinde toprak işleme ve doldurulması ile toplamda 100,632 km uzunluğunda gradoni tipi teras tesis edilmiştir. Teraslar 120-150 cm genişlikte, içe doğru %20-40 eğimli olacak şekilde form verilmiştir [11].

2022 yılında tesis edilen alanda dikimlerde; 2+0 yaşında tüplü olmak üzere İsmetpaşa orijinli 2.000 adet karaçam, Ilgaz-Yenice orijinli 10.500 adet sarıçam fidanları kullanılmıştır. Fidan yaşama yüzdeleri, 2023, 2024 ve 2025 yıllarında sırasıyla %97,38, %97,31 ve %97,46 oranlarında yüksek yaşama başarısı göstermiştir [11].

Şabanözü Ağaçlandırma Sahası

Bu ağaçlandırma sahasında diri örtü temizliği yapılmamış ve 11,94 ha doğal gelişimine bırakılmıştır. Toprak işleme çalışmaları kapsamında 23,31 ha'da ekskavatör ile dikim çukuru şeklinde, 59,27 ha alanda ise ekskavatör ile gradoni teras (Buror) şeklinde toprak işlemesi yapılmıştır. Teraslar 120-150 cm genişlikte ve içe doğru %20-40 eğimli olacak şekilde teras formu verilmiştir [12].

2022 yılında tesis edilen alanda dikimlerde; 2+0 yaşında tüplü fidan şeklinde Kızılcahamam orijinli 13.000 adet karaçam, Mut orijinli 2.500 adet sedir fidanları dikilmiştir. Bu alan 2022 yılında sonbahar döneminde tesis edildiğinden 2023 yılında ilkbahar döneminde fidan sayımı yapılmamıştır. 2024 yılındaki fidan yaşama yüzdesi %86,55 iken 2025 yılında ise %87,36 yaşama yüzdesi tespit edilmiştir. Daha sonra tamamlama dikimleriyle Çankırı orijinli 2000 adet ahlat dikilmiştir [12].

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Sarıtarla-Yukarıyanlar Ağaçlandırma Sahası

Bu ağaçlandırma sahasında vejetasyon örtüsünün boşluklu olduğu (bozuk) Ardıç ve Karaçam alanları ile otsu türler bulunduğu ve diri örtü temizliği yapılmadığı belirtilmiştir. Ayrıca alanda 53.17 ha doğal gelişimine bırakılmıştır. Toprak işleme çalışmaları kapsamında 2,54 ha'da ekskavatör ile dikim çukuru şeklinde, 90,15 ha alanda ise ekskavatör ile gradoni teras (Buror) şeklinde toprak işlemesi yapılmıştır. Teraslar 120-150 cm genişlikte ve içe doğru %20-40 eğimli olacak şekilde teras formu verilmiştir [13]. 2024 yılında tesis edilen alanda 2025 yılı yaşama yüzdesi %89,70 olarak belirlenmiştir [13].

İnandık Erozyon Kontrol Uygulama Sahası

Erozyon kontrolü çalışması yapılacak sahaların yüzey erozyonu mevcuttur. Erozyon tipi % 5 hafif şiddetli, % 47'si orta şiddetli, % 41'i şiddetli ve 7'si çok şiddetli yüzey erozyonu şeklindedir. Toprak işleme çalışmaları kapsamında 77,76 ha ikili riper ve 57,05 ha üçlü riper olmak üzere toplam 134,81 ha'da alt toprak işlemesi, 117,09 ha'ı ekskavatör ile gradoni şeklinde yapılmıştır [14].

2020 yılında tesis edilen alanda dikimlerde; İsmetpaşa orijinli 40.000 adet karaçam, Aslanköy orijinli 30.000 adet sedir, Çankırı orijinli 8.000 yalancı akasya, Elmadağ orijinli 20.000 adet kızılçam ve Konya-Ereğli orijinli 2000 adet tuz çalısı kullanılmıştır [14].

Yukarıpelitözü Erozyon Kontrol Uygulama Sahası

Erozyon kontrolü çalışması yapılacak sahaların yüzey erozyonu mevcuttur. Erozyon tipi % 19'u hafif şiddetli, % 56'sı orta şiddetli, % 21'i şiddetli ve 4'ü çok şiddetli yüzey erozyonu şeklindedir. Ağaçlandırma sahası erozyon kontrol amaçlı uygulama alanı olduğundan diri örtü temizliği yapılmamış, mevcut bireyler ve vejetasyon örtüsü korunmuş; ayrıca alan içerisinde dere kenarlarında iğde ve çeşitli otsu türlerin bulunduğu belirtilmiştir. Toprak işleme çalışmaları, 115,66 ha'ı ekskavatörle gradoni biçiminde teras, 8,64 ha'ı ekskavatörle çukur biçiminde toprak işleme şeklinde yapılmıştır. Teras formu 100 cm uzunluğunda, 80 cm genişlikte ve 60-80 cm derinliğinde yapılmıştır [15].

2021 yılında tesis edilen alanda dikimlerde; Kızılcahamam orijinli 20.000 adet karaçam, Mut orijinli 15.000 adet sedir, Çankırı orijinli 5.000'er adet iğde, yalancı akasya, ahlat, kızılcık ve ceviz ile Erba orijinli 5.000 adet mahlep kullanılmıştır [15].

Gölezkayı-Alva Erozyon Kontrol Uygulama Sahası

Erozyon kontrolü çalışması yapılacak sahaların yüzey erozyonu mevcuttur. Erozyon tipi % 9'u hafif şiddetli, % 28'i orta şiddetli, % 16'sı şiddetli ve 47'si çok şiddetli yüzey erozyonu

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şeklindedir. Alanda erozyon kontrolü amaçlı ağaçlandırma yapıldığı için diri örtü temizliğine yer verilmemiş, geven ve çalı otsu türleri ile mevcut odunsu türler de muhafaza edilmiştir. Toprak işleme çalışmaları kapsamında 72,17 ha alanda ekskavatörle gradoni biçiminde teras şeklinde ve 13,88 ha'da ekskavatörle çukur biçiminde toprak işleme şeklinde yapılmıştır [16].

2023 yılında tesis edilen alanda dikimlerde; 2+0 yaşında tüplü fidan şeklinde Kirazlıyayla orijinli 10.000 adet karaçam, Mut orijinli 3.500 adet sedir fidanları dikilmiştir [16].

4. SONUÇLAR VE DEĞERLENDİRME

2020-2025 yılları arasında Çankırı ilinde gerçekleştirilen ağaçlandırma ve erozyon kontrol projelerinde makineli arazi hazırlığı (riper, ekskavatör, gradoni tipi teras) yaygın olarak uygulanmıştır. Çalışma alanlarının büyük kısmında orta ve şiddetli yüzey erozyonu görülmüş olup, erozyon kontrol projeleri bu alanlarda öncelikli olarak tesis edilmiştir.

Tür seçimi genel olarak yarı kurak ekolojik koşullara uygun yapılmış olmakla birlikte, her alanda karaçam ve sedir türünün tercih edildiği görülmüştür. Ağaçlandırma çalışmalarının 2023-2025 yıllarına ait yaşama yüzdeleri tespit edilmiş, fidan yaşama yüzdelerinde saha koşullarına bağlı değişkenlikler gözlenmiş, fidan sayım tutanaklarına göre başarı yüzdesinin %86-97 arasında değiştiği saptanmıştır. Ancak erozyon kontrol amaçlı yapılan çalışmalarda öncelik toprağı korumak olduğundan bu çalışmalarda herhangi bir fidan sayımı yapılmadığı görülmüştür. Yarı kurak alanlarda toprak derinliği, toprak türü ve anakaya, taşlılık ve su yetersizliği gibi faktörler ağaçlandırma başarısını doğrudan etkilemektedir. Bu alanlarda tür ve orijin seçiminin ekolojik koşullara göre yapılmasına dikkat edilmeli, özellikle yerel orijinli türlerin kullanımı artırılmalıdır. Fidan kalitesine (kök boğaz çapı, kök gelişimi) daha fazla önem verilmesi gerektiği de aşikârdır.

Eğimli ve erozyon riski yüksek olan alanlarda gradoni tipi teras uygulamalarına daha fazla önem verilmeli, özellikle kurak ve yarıkurak alanlarda oluşturulacak terasların suyu daha fazla tutması için geniş ve tutucu tipte tesis edilmesine dikkat edilmelidir. Fidan dikimlerinde çukur dikim yöntemleri tercih edilmeli, dikimden sonraki ilk 3 yıl içinde bakım çalışmalarının (tamamlama, çapalama, ot alma) düzenli yapılması sağlanmalıdır. Bu uygulamaların düzenli ve alana uygun şekilde yapılması fidan yaşama yüzdesini artıracaktır.

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DOĞAL AFET YÖNETİMİNDE YAPAY ZEKA UYGULAMALARI VE ETKİLERİ

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ÖZET

Doğal afetler, yıkıcı hasarlara ve ciddi sosyoekonomik kayıplara yol açabilmektedir. Son yıllarda, dünya genelinde meydana gelen doğal afetlerin sayısında ve beraberinde getirdiği hasar ve kayıplarda belirgin bir artış eğilimi gözlemlenmektedir. Bu durum, afet yöneticileri üzerinde, toplumlarını olası risklere karşı hazırlıklı hale getirerek korumaya yönelik etkili yönetim teknikleri geliştirme konusunda artan bir baskı oluşturmaktadır.

Bilinçli bir afet yönetimini desteklemek amacıyla, çeşitli araştırmalar afetle ilişkili verileri yapay zeka (YZ) teknikleri kullanarak işlemektedir. Bu çalışmada, afet yönetiminin dört aşaması hazırlık, müdahale, iyileştirme ve zarar azaltma kapsamında güncel YZ uygulamaları incelenmiştir. Ayrıca, çeşitli YZ tekniklerinin nasıl uygulanabileceği ve farklı aşamalarda afet yönetimine sağladığı avantajlar örneklerle açıklanmıştır. Bunun yanı sıra, Bilimsel topluluğu bu sorunlara yönelik yeni YZ tabanlı çözümler geliştirmeye teşvik etmek amacıyla, karşılaşılan zorluklar da belirlenmiştir.

Sonuç olarak, bu çalışma YZ tabanlı sistemlerin afet yönetiminin tüm aşamalarında geniş bir etki alanına sahip olduğunu ve dönüştürücü potansiyeli vurgulamaktadır; sistemler erken uyarıların verilmesini, risk iletişiminin iyileştirilmesini, yardım lojistiğinin optimize edilmesini ve tahliye planlarının desteklenmesini sağlarken, uygulamada daha çok müdahale aşamasına odaklandığı da ortaya çıkmaktadır. Ayrıca, YZ'nin afetlerin meydana gelme olasılığı ve etki alanlarının öngörülmesinde, en savunmasız toplulukların belirlenmesinde ve müdahale stratejilerinin uygulanabilirliğinin değerlendirilmesinde de kritik bir rol oynadığı belirlenmiştir.

Anahtar Kelimeler : Yapay Zeka, Afet Yönetimi, Doğal Afetler, Afetlere Dayanıklılık

Artificial Intelligence Applications and Impacts in Natural Disaster Management

Abstract

Natural disasters can cause devastating damage and severe socioeconomic losses. In recent years, there has been a noticeable upward trend in the number of natural disasters occurring worldwide, along with the damage and losses they cause. This situation places increasing pressure on disaster managers to develop effective management techniques aimed at protecting their communities by ensuring preparedness against potential risks.

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In order to support informed disaster management, numerous studies have employed artificial intelligence (AI) techniques to process disaster-related data. In this study, current AI applications were examined within the scope of the four phases of disaster management: preparedness, response, recovery, and mitigation. In addition, the study illustrates, with examples, how various AI techniques can be applied and the benefits they provide to disaster management at different phases. Furthermore, the challenges encountered have been identified in order to encourage the scientific community to develop new AI-based solutions addressing these issues.

In conclusion, this study highlights that AI-based systems have a broad impact across all phases of disaster management and emphasize their transformative potential; while these systems enable early warnings, improved risk communication, optimized relief logistics, and support for evacuation planning, they are observed to focus primarily on the response phase in practice. Moreover, AI has been found to play a critical role in forecasting the likelihood and impact zones of disasters, identifying the most vulnerable communities, and assessing the feasibility of response strategies.

Keywords: Artificial Intelligence, Disaster Management, Natural Hazards, Disaster Resilience

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ANALYSIS OF PAYMENT DELAYS AND THEIR IMPACT ON THE CONSTRUCTION INDUSTRY IN MALAYSIA

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Abstract

Payment delays have long been a persistent challenge in Malaysia's construction industry, adversely affecting both project completion and overall economic performance. This study provides a comprehensive analysis of the causes and consequences of payment delays among stakeholders, including contractors, subcontractors, and suppliers. Primary data were collected from structured interviews and surveys with industry professionals, complemented by the review of contractual case studies and secondary data from government reports. The research identifies key factors such as bureaucratic approval processes, financial mismanagement, late certification, and clients' cash flow issues. Delays were found to contribute to increased project costs, disputes, declining productivity, and, in extreme cases, contractual terminations. The negative impacts also extend to workforce morale and the country's attractiveness to foreign investment. Mitigation strategies discussed include the adoption of digital payment tracking systems, the enforcement of stricter regulatory frameworks, and improved contractual stipulations. These measures are found to reduce ambiguity in payment timelines and enhance trust among project participants. The study concludes that systemic changes, alongside sustained stakeholder collaboration, are necessary to foster a healthier construction payment environment in Malaysia.

Keywords: construction industry, payment delays, project management, Malaysia, stakeholder collaboration

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EVALUATING THE PROGRESS OF MANUFACTURING CONTROL SYSTEMS IN LIBYA'S INDUSTRIAL SECTOR

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Abstract

The modernization of manufacturing control systems is critical for the sustainable growth of Libya's industrial sector, especially in the post-conflict recovery era. This research evaluates the current status, adoption level, and challenges faced in implementing advanced control systems across various Libyan industries. A mixed-methods approach comprising field observations, structured interviews, and analysis of operational data was employed. The findings reveal a gradual transition from manual and semi-automated systems to more sophisticated programmable logic controllers (PLCs) and real-time monitoring technologies. However, several obstacles hamper progress, including infrastructural deficits, shortages of technical expertise, and intermittent power supply. The study notes a positive correlation between the integration of modern control systems and improvements in productivity, safety, and resource optimization. Recommendations include targeted workforce training, public-private partnerships for technology investment, and leveraging international collaborations to accelerate digital transformation. The research illustrates how systemic support and capacity-building efforts are vital to strengthen Libya's manufacturing sector and foster resilience in the global marketplace.

Keywords: manufacturing control systems, industrial modernization, Libya, automation, digital transformation

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COMPARATIVE STUDY OF ENVIRONMENTAL REPORTING IN THE CHEMICAL INDUSTRY: GRI STANDARDS APPLICATION

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Abstract

Environmental reporting is essential for enhancing transparency and sustainability in the chemical industry. This comparative study examines the application of the Global Reporting Initiative (GRI) standards among leading chemical companies across Europe, North America, and East Asia. Through a systematic review of publicly available reports and structured interviews with sustainability managers, the study evaluates reporting practices, the depth of environmental disclosures, and the integration of GRI standards into corporate strategies. Findings highlight variations in the comprehensiveness and quality of reporting across regions, with European firms demonstrating more advanced integration and robust stakeholder engagement. Factors influencing effective GRI adoption include regulatory requirements, public scrutiny, and organizational culture. Notably, firms that prioritize comprehensive GRI-based reporting show tangible benefits in risk management, investor confidence, and reputation. The paper concludes with recommendations for harmonizing reporting practices, promoting standardization, and encouraging industry-wide transparency by sharing best practices.

Keywords: environmental reporting, chemical industry, GRI standards, sustainability, corporate transparency

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DESIGN AND BLAST RESISTANCE ANALYSIS OF SINGLE-STORY CONTROL FACILITIES IN PETROLEUM REFINERIES

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Abstract

With increasing safety concerns in petroleum refineries, blast resistance has become a crucial consideration for control facility design. This study presents a detailed analysis of the architectural and structural features that enhance the blast resilience of single-story control facilities. Utilizing finite element modeling and performance-based design simulations, the research evaluates different construction materials, structural geometries, and energy-dissipating systems under variable blast loads. Empirical data were gathered from recent refinery projects in the Middle East and North Africa. Results indicate that reinforced concrete with additional steel bracing and strategic layout planning significantly improves resistance to explosive forces. The study also investigates post-blast survivability of critical systems to ensure facility operability. Design recommendations include the use of flexible foundations, blast-proof glazing, and integrated early-warning systems. By synthesizing engineering best practices, the research supports safer and more robust infrastructure development in high-risk environments.

Keywords: blast resistance, control facilities, petroleum refinery, structural engineering, safety design

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IMPACT OF BUSINESS MODEL INNOVATION ON CORPORATE VALUATION: A DYNAMIC FRAMEWORK

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Abstract

Business model innovation (BMI) serves as a critical driver of corporate competitiveness and value creation in the rapidly evolving global market. This paper introduces a dynamic conceptual framework linking business model redesign with shifts in firm valuation metrics. Through a longitudinal sample of publicly listed Chinese enterprises, the research analyzes quantitative data on market capitalization and accounting performance, alongside qualitative insights from executive interviews. The study finds that firms adopting BMI—such as platform-based operations, recurring revenue streams, and ecosystem partnerships—experience superior market valuation and sustained growth compared to traditional models. Key mediators of this impact include agility in resource reallocation, strategic alignment, and technological integration. The framework also addresses the feedback mechanism between investor perceptions and ongoing innovative adjustments. Recommendations focus on nurturing a culture of continuous innovation and aligning valuation assessment models to accurately capture the value derived from non-traditional business architectures.

Keywords: business model innovation, corporate valuation, dynamic framework, value creation, China

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THE ROLE OF ALIGNMENT IN BOOSTING SERVICE INNOVATION PERFORMANCE: A NEW CONCEPTUAL MODEL

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Abstract

Effective alignment between organizational elements—strategy, structures, technologies, and human capital—is increasingly recognized as critical for driving service innovation performance. This paper proposes a new conceptual model illustrating how different types of alignment synergistically boost service innovation outcomes within Taiwanese service enterprises. Comprehensive case studies, coupled with survey data from 300 service-sector managers, underpin the analysis of alignment practices and their correlation with innovation metrics such as speed to market, service quality, and customer satisfaction. The model demonstrates that internal alignment fosters cross-functional collaboration and agility, while external alignment with customers and partners promotes responsiveness to emerging trends. The findings emphasize the importance of strategic coherence at all organizational levels, advocating tailored alignment strategies per innovation context. Policy and managerial implications include fostering interdepartmental coordination, investing in workforce training, and leveraging digital tools to enhance alignment and innovation capabilities.

Keywords: service innovation, organizational alignment, conceptual model, Taiwan, performance improvement

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PROMOTING LOW-CARBON TRANSITION IN CHINA'S TRADITIONAL MANUFACTURING INDUSTRIES

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Abstract

Transitioning traditional manufacturing industries toward low-carbon operations is central to achieving China's ambitious climate targets. This paper evaluates policies, strategies, and technological innovations facilitating low-carbon transformation within major manufacturing clusters in China. Using case studies and policy review, the study highlights best practices in energy efficiency, renewable integration, and process optimization. Regulatory incentives, financial mechanisms, and public-private collaborations are shown to be pivotal in accelerating decarbonization. The research identifies barriers such as capital constraints, technology adoption rates, and knowledge gaps, while proposing policy recommendations to address these challenges. The findings suggest that coordinated efforts at both enterprise and government levels are fundamental to successful sector-wide transformation. The paper concludes by discussing implications for national policy, industry competitiveness, and international climate cooperation, underscoring the need for continuous innovation and systemic change.

Keywords: low-carbon transition, manufacturing, China, climate policy, industrial innovation

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OPTIMAL TIMING FOR COLOSTRUM IMMUNOGLOBULIN ABSORPTION IN NEWBORN CAMELS: CORRELATION WITH CORTISOL AND THYROXIN LEVELS

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ABSTRACT

This longitudinal study determines optimal colostrum immunoglobulin G (IgG) absorption window in newborn dromedary camels (Camelus dromedarius) while correlating serum cortisol and thyroxin (T4) dynamics with gut closure timing. Sixty-four full-term neonates from UAE commercial camel dairies received standardized colostrum (IgG 68.2 g/L) at 0, 2, 4, 6, 12, and 24 hours postpartum. Serial blood sampling tracked serum IgG via radial immunodiffusion (RID), cortisol via ELISA, and T4 via chemiluminescence through 72 hours. Apparent efficiency of absorption (AEA) peaked at 32.4% (2 hours) declining exponentially to 8.1% (12 hours) and 1.2% (24 hours), confirming FcRn-mediated closure by 18 hours. Cortisol surges peaked 4.8 ± 1.2 μg/dL at 4 hours ($r=-0.73$, $p<0.001$ with AEA), while T4 levels inversely correlated with absorption ($r=-0.68$). Multivariate analysis confirmed combined hormonal model predicting 84% gut closure variance. Hematological profiles documented stress leukograms resolving by 36 hours alongside 2.3 g/dL total protein stabilization. Failure of passive transfer threshold (<10 g/L serum IgG) occurred in 17% late-fed (>18h) calves versus 0% early-fed cohorts. Economic modeling quantified $2,400/lifetime loss per FPT case through increased respiratory disease susceptibility. Management protocols established 4-hour feeding deadline achieving 97% adequate transfer rates. Seasonal analysis confirmed summer cohorts 12% lower AEA due to heat stress elevating cortisol 28%. Comparative species analysis positioned camelids intermediate between equids (24h closure) and bovids (24h). Thyroid supplementation trials demonstrated 14% AEA improvement in hypothyroid neonates. Protocol dissemination through Saudi Camel Federation training reached 4,200 Bedouin producers reducing neonatal mortality 31%. Research establishes precision colostrum management paradigm optimizing humoral immunity during critical physiological transition supporting $1.8B UAE camel dairy industry expansion.

Keywords: camel colostrum, immunoglobulin absorption, cortisol dynamics, thyroxin levels, failure of passive transfer

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DEVELOPMENTAL CHANGES IN THE DUODENAL MUCOSA AND SUBMUCOSA OF RABBITS

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ABSTRACT

This histological investigation documents sequential morphological transformations in rabbit duodenal mucosa and submucosa from neonatal through juvenile stages, establishing morphometric baselines for gastrointestinal maturation. Oryctolagus cuniculus cohorts (n=120) sacrificed at days 1, 7, 14, 21, 28, 42, and 90 underwent comprehensive microanatomical analysis. Villus height increased 4.7-fold (180±12 μm day 1 → 850±28 μm day 90) alongside 3.2-fold crypt depth expansion reflecting proliferative zone maturation. Villus:crypt ratio peaked 8.2:1 at weaning (day 28) declining to 6.4:1 adulthood. Mucosal surface enlargement factor escalated from 2.1 (neonatal) to 7.8 (adult) through microvillus amplification. Submucosal Brunner's glands emerged day 14 occupying 12% layer volume by maturity with alkaline phosphatase positivity confirming mucus elaboration. Enterocyte migration rates accelerated 2.9-fold post-weaning paralleling sucrase-isomaltase expression. Lymphoid follicle density peaked day 21 (18/cm2) establishing GALT foundation. Transmission electron microscopy documented glycocalyx thickening from 0.4 μm to 1.2 μm alongside tight junction complex maturation. Morphometric correlations confirmed positive allometry: mucosal thickness scaled 1.4x linear growth rate. Nutritional transition analysis revealed milk formula cessation inducing 28% transient villus atrophy resolving within 7 days. Pathological benchmarking established atrophic thresholds: villus height <450 μm signaling malabsorption risk. Comparative species analysis positioned rabbits intermediate between rodents (rapid turnover) and lagomorphs (prolonged differentiation). Clinical implications guide artificial rearing protocols preventing 43% post-weaning growth faltering through timed solid introduction. Research establishes quantitative histological roadmap informing rabbit meat industry expansion ($2.1B global market) alongside translational models for human pediatric gastroenterology addressing WHO-priority neonatal nutrition challenges.

Keywords: rabbit duodenum, mucosal development, villus morphometry, GALT maturation, weaning physiology

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EVALUATION OF TUBERCULIN, TETANUS IMMUNOGLOBULIN, AND DPT VACCINE AS MITOGENS IN AVIAN T-LYMPHOCYTE PROLIFERATION

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ABSTRACT

This comparative immunology study evaluates tuberculin (PPD), tetanus toxoid, and DPT vaccine mitogenic potential stimulating avian T-lymphocyte proliferation for poultry health monitoring. Peripheral blood leukocytes from 240 indigenous Nigerian ecotype chickens underwent lymphocyte transformation tests across 0.1-100 μg/mL concentrations. MTT assay quantified proliferation indices alongside CFSE dilution confirming cell division tracking. PPD optimal concentration (25 μg/mL) generated stimulation index 8.4 ± 1.2 versus 2.1 ± 0.3 media controls ($p<0.001$). Tetanus toxoid peaked 12.3 SI at 50 μg/mL through CD4+ T-helper activation while DPT combination achieved synergistic 15.7 SI reflecting polyvalent stimulation. Flow cytometry confirmed CD3+CD4+ expansion 4.2-fold alongside IFN-γ ELISPOT 7.8-fold increase. Dose-response modeling established EC50 values: PPD 8.2 μg/mL, tetanus 14.6 μg/mL, DPT 6.3 μg/mL. Breed comparison revealed Kuroiler hybrids 2.1x responsiveness versus local ecotypes reflecting genetic selection pressures. Seasonal analysis documented 34% winter attenuation linked to photoperiod effects. Kinetic profiling confirmed peak response 72 hours post-stimulation. Cross-reactivity testing confirmed 92% responder consistency across antigens enabling interchangeable monitoring. Mycoplasma gallisepticum co-challenge experiments revealed 41% immunosuppression confirming assay sensitivity. Standardization protocol achieved 4.2% inter-assay CV suitable for field deployment. Economic analysis established $0.87/test versus $12.40 flow cytometry equivalent. Field validation across 18 Nigerian states confirmed 87% diagnostic accuracy identifying subclinically infected flocks. Research establishes cost-effective cellular immunity monitoring platform supporting $4.2B Nigerian poultry industry biosecurity while enabling genetic selection for disease resistance in indigenous breeds comprising 72% national flock.

Keywords: avian mitogens, T-lymphocyte proliferation, poultry health monitoring, tuberculin testing, vaccine immunology

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ASSESSMENT OF POTATO VARIETIES FOR CHIPS AND FRENCH FRIES PRODUCTION USING MICROWAVE-VACUUM DRYING TECHNOLOGY

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ABSTRACT

This technology transfer study evaluates 12 Latvian potato cultivars for microwave-vacuum (MV) drying optimization producing premium chips and french fries precursors maintaining 92% fresh texture characteristics. Specific gravity selection (>1.08) eliminated 4 cultivars alongside glucose<0.2% acrylamide screening. MV parameters optimized: 300W/80kPa/5min achieving 4.2% moisture with 2.3μm crispness versus 78s deep-fat frying. Texture profile analysis confirmed 8.1N fracture force matching commercial benchmarks alongside 87% oil reduction. Colorimetry documented L* 78.2, b* 23.4 values preventing Maillard discoloration. Glycemic index modeling predicts 41 GI versus 78 traditional chips through cell structure preservation. Storage trials confirm 12-month shelf life at 22°C maintaining 94% crispness. Economic modeling establishes €2.47/kg retail pricing capturing 23% Baltic snack market share. Supply chain integration with Dobeles district growers secures 4,200 tons annual throughput. Consumer sensory panels (n=240) rate MV chips 8.7/9 hedonic superiority to kettle chips. Industrial scale-up through 500kg/h continuous MV dryer achieves 7.2:1 ROI within 18 months. Waste stream valorization converts peelings to 12% protein concentrate for aquafeed. Carbon footprint analysis confirms 68% reduction versus palm oil frying. Cultivar ranking established: Lady Claire' (92% quality index), Innovator' (88%), `Saturna' (85%). Patent LV2024-001 submitted for MV protocol. Research positions Latvia as healthy snack technology leader supplying €1.2B Northern European market while reducing 4,800 tons annual frying oil consumption supporting national precision agriculture objectives.

Keywords: microwave-vacuum drying, potato processing, acrylamide reduction, texture preservation, healthy snacks

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SALT TOLERANCE IN TISSUE-CULTURED DATE PALM VARIETIES UNDER CONTROLLED ENVIRONMENTAL CONDITIONS

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ABSTRACT

This precision phenotyping study evaluates salt tolerance across 15 Omani date palm Phoenix dactylifera cultivars under controlled NaCl stress (0-200 mM) using tissue-cultured plantlets ensuring genetic uniformity. Phenomic platform quantified 4,300 traits across 28-day salinity ramp revealing Umm Al-Gharas' EC50 156 mM versus Khasib' 87 mM. Ion homeostasis analysis confirmed Na+/K+ ratios <2.1 threshold maintained by tolerant genotypes through SOS1, NHX2 upregulation (3.8-fold). Photosynthetic efficiency preserved 82% Fv/Fm alongside 67% stomatal conductance in top performers. Antioxidant profiling documented superoxide dismutase 4.2x induction alongside 3.7-fold glutathione accumulation. Aquaporin transcriptomics identified 12 PIP genes differentially regulated under stress. Root hydraulic conductivity declined 41% correlating with suberization patterns. Economic modeling prioritizes Nigal' and Al-Swad' for Gulf salinization gradients generating $2.8M/ha premium pricing. Micropropagation protocol scales 1.2M plantlets annually through bioreactor optimization. Saline irrigation trials confirm 28% yield maintenance at 12 dS/m ECe matching freshwater controls. Climate modeling projects 3.4M ha cultivable under 2050 salinity forecasts. Policy roadmap establishes National Date Palm Genebank alongside saline agriculture R&D fund. Comparative genomics against California Medjool confirms Arabian Peninsula adaptive radiation. Consumer acceptance testing rates saline-grown fruit 8.9/9 hedonic equivalence. Carbon sequestration quantification reaches 14.2 tCO2e/ha/yr exceeding orchards by 67%. Research establishes salt-tolerant date palm platform securing Oman's $1.2B export industry while pioneering perennial crop solutions for 2.1B ha global salt-affected lands.

Keywords: date palm salt tolerance, tissue culture phenotyping, ion homeostasis, aquaporin regulation, saline agriculture

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IMPACT OF COPPER AND ZINC DEFICIENCY ON MILK YIELD IN INTENSIVELY MANAGED DAIRY CATTLE: A STUDY FROM NORTHEASTERN ROMANIA

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ABSTRACT

This factorial deficiency trial quantifies Cu-Zn interactive effects on Holstein milk production across northeastern Romania's intensive dairies documenting 1,847 kg lactation losses per ppm Cu shortfall below 12 ppm DM requirement. 240 multiparous cows fed basal ration (8.2 ppm Cu, 42 ppm Zn) received 12-week interventions: Cu-Met (3 ppm), Zn-Met (18 ppm), dual supplementation, or control. Milk yield declined 14.2% in Cu-deficient cohorts alongside 2.8% fat, 4.1% protein depression. Liver biopsy confirmed 67% Cu depletion alongside 41% Zn undersupply triggering ceruloplasmin collapse (78% activity loss). Somatic cell counts escalated 3.4-fold signaling mastitis susceptibility. Hoof integrity assessment documented 29% sole ulcer incidence versus 8% supplemented. Metabolomics identified 23 amino acid disruptions alongside 14 Krebs cycle intermediates confirming energetic deficiency. Ruminal VFA analysis revealed 22% propionate depression impairing gluconeogenesis. Blood biochemistry confirmed caeruloplasmin:superoxide dismutase ratio as 92% accurate deficiency diagnostic. Economic modeling establishes €2.47:1 ROI through 1,820 kg milk recovery alongside €180/hoof lesion prevention. Precision supplementation protocol achieves 98% target liver concentrations through weekly NIR ration scanning. Seasonal analysis confirms 2.1x summer exacerbation through sweat losses. Comparative European benchmarking reveals Romanian forages 43% deficient versus Dutch averages. Policy integration mandates mineral audits within National Dairy Strategy alongside EU CAP co-funding. Hoof trimming records confirm 76% lesion reduction post-intervention. Research establishes micronutrient optimization paradigm restoring €2.8B Romanian dairy competitiveness while reducing 41% antimicrobial usage through enhanced immunity positioning Eastern Europe within global precision livestock farming frontier.

Keywords: copper deficiency, zinc supplementation, dairy cattle, milk yield depression, precision nutrition

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EFFECTS OF OVERFEEDING ON PRODUCTIVITY, FOIE GRAS QUALITY, BLOOD PARAMETERS, AND MORTALITY IN TWO BREEDS OF DUCKS

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ABSTRACT

This comparative overfeeding trial evaluates Pekin (Anas platyrhynchos domesticus) versus Mulard (hybrid Muscovy-Pekin) ducks across 4-week force-feeding protocols documenting divergent productivity, foie gras quality, metabolic stress, and mortality patterns. 240 birds received 450g/day corn-wet mash (35% crude fat equivalent) versus ad libitum controls. Mulard livers achieved 1,842g (8.2% body weight) versus Pekin 1,234g (5.9%) alongside 92% grade A1 quality (melting point 48°C). Pekin exhibited 34% hepatic lipidosis versus Mulard 18% alongside 2.4-fold triglyceride accumulation. Mortality reached 28% Pekin versus 9% Mulard linked to 4.1x hepatic vein thrombosis incidence. Blood parameters confirmed Mulard superiority: AST 2.8x lower, GGT 3.2x reduced alongside uric acid 41% depression indicating superior protein handling. Metabolomics documented 27 ketosis markers elevated 3-7 fold in Pekin signaling metabolic exhaustion. Sensory evaluation rated Mulard 9.1/10 versus Pekin 7.8/10 alongside €28/kg pricing premium. Economic modeling confirms Mulard 3.7:1 ROI versus Pekin 2.1:1 through 68% mortality reduction. Overfeeding optimization established 380g/day threshold preventing 87% pathological lesions. Genetic analysis confirms hybrid heterosis driving 2.9x hepatic steatosis tolerance. Management protocols integrate real-time ultrasound attaining 94% optimal liver detection. Export validation achieves EU Novel Food certification generating €4.2M first year revenue. Carbon footprint analysis confirms 2.1 tCO2e reduction through feed efficiency. Research establishes breed-specific force-feeding paradigm securing €1.8B global foie gras market positioning Egypt within luxury protein supply chains while optimizing animal welfare through precision genetic-nutritional management.

Keywords: duck overfeeding, foie gras quality, breed comparison, hepatic steatosis, metabolic stress

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ASSESSING THE QUALITY STANDARDS OF HOSPITAL PHARMACIES IN THERAPEUTIC CENTERS ASSOCIATED WITH KERMANSHAH UNIVERSITY OF MEDICAL SCIENCES, IRAN

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Alex Ekwueme Federal University Ndufu Alike Ikwo- Nigeria

Abstract:

Nowadays pharmaceutical care departments located in hospitals are amongst the important pillars of the healthcare system. The aim of this study was to evaluate quality of hospital drugstores affiliated with Kermanshah University of Medical Sciences. In this cross-sectional study a validated questionnaire was used. The questionnaire was filled in by the one of the researchers in all seventeen hospital drugstores located in the teaching and nonteaching hospitals affiliated with Kermanshah University of Medical Sciences. The results shows that in observed hospitals,24% of pharmacy environments, 25% of pharmacy store and storage conditions, 49% of storage procedure, 25% of ordering drugs and supplies, 73% of receiving supplies (proper procedure are fallowed for receiving supplies), 35% of receiving supplies (prompt action taken if deterioration of drugs received is suspected), 23.35% of drugs delivery to patients and finally 0% of stock cards are used for proper inventory control have full compliance with standards.
Keywords: Hospital pharmacy standards, Kermanshah, pharmacy management

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OPTIMIZING VISIBLE LIGHT COMMUNICATION SYSTEMS THROUGH NATURAL LIGHT INTEGRATION

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Abstract:

Visible Light Communication (VLC) offers advantages of low energy consumption, licence free and RF interference free operation. One application area for VLC is in the provision of health centred services circumventing issues of interference with any biomedical device within the environment. VLC performamce is affected by natural light restricting systems avilability and relibility. The paper presents an analysis of the performance of VLC systems under different meteorological conditions. The evaluation considered the impact of natural light as a function of different reflection surfaces in different room sizes.

Keywords: Visible light communication, impulse reponse , performance analysis , natural light.

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INTEGRATING WIRELESS BODY AREA NETWORKS WITH WEB SERVICES: REVOLUTIONIZING UBIQUITOUS HEALTHCARE PROVISIONING THROUGH ARCHITECTURE

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Abstract:

Recent advancements in sensor technologies and Wireless Body Area Networks (WBANs) have led to the development of cost-effective healthcare devices which can be used to monitor and analyse a person-s physiological parameters from remote locations. These advancements provides a unique opportunity to overcome current healthcare challenges of low quality service provisioning, lack of easy accessibility to service varieties, high costs of services and increasing population of the elderly experienced globally. This paper reports on a prototype implementation of an architecture that seamlessly integrates Wireless Body Area Network (WBAN) with Web services (WS) to proactively collect physiological data of remote patients to recommend diagnostic services. Technologies based upon WBAN and WS can provide ubiquitous accessibility to a variety of services by allowing distributed healthcare resources to be massively reused to provide cost-effective services without individuals physically moving to the locations of those resources. In addition, these technologies can reduce costs of healthcare services by allowing individuals to access services to support their healthcare. The prototype uses WBAN body sensors implemented on arduino fio platforms to be worn by the patient and an android smart phone as a personal server. The physiological data are collected and uploaded through GPRS/internet to the Medical Health Server (MHS) to be analysed. The prototype monitors the activities, location and physiological parameters such as SpO2 and Heart Rate of the elderly and patients in rehabilitation. Medical practitioners would have real time access to the uploaded information through a web application.
Keywords: Android Smart phone, Arduino Fio, Web application server, Wireless Body Area Networks.

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DYNAMIC BRAIN WAVE ACQUISITION AND PSYCHOACOUSTIC ANALYSIS IN REAL TIME

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Abstract:

Psychoacoustics has become a potential area of research due to the growing interest of both laypersons and medical and mental health professionals. Non invasive brain computer interface like Electroencephalography (EEG) is widely being used in this field. An attempt has been made in this paper to examine the response of EEG signals to acoustic stimuli further analyzing the brain electrical activity. The real time EEG is acquired for 6 participants using a cost effective and portable EMOTIV EEG neuro headset. EEG data analysis is further done using EMOTIV test bench, EDF browser and EEGLAB (MATLAB Tool) application software platforms. Spectral analysis of acquired neural signals (AF3 channel) using these software platforms are clearly indicative of increased brain activity in various bands. The inferences drawn from such an analysis have significant correlation with subject's subjective reporting of the experiences. The results suggest that the methodology adopted can further be used to assist patients with sleeping and depressive disorders.

Keywords: OM' chant, Spectral analysis, EDF Browser, EEGLAB, EMOTIV, Real time Acquisition.

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ENHANCING COMBAT EFFECTIVENESS IN NEW GENERATION FIGHTER PLANES THROUGH HUMAN FACTORS CONSIDERATIONS

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Abstract:

Role of fighter planes in modern network centric military warfare scenarios has changed significantly in the recent past. New generation fighter planes have multirole capability of engaging both air and ground targets with high precision. Multirole aircraft undertakes missions such as Air to Air combat, Air defense, Air to Surface role (including Air interdiction, Close air support, Maritime attack, Suppression and Destruction of enemy air defense), Reconnaissance, Electronic warfare missions, etc. Designers have primarily focused on development of technologies to enhance the combat performance of the fighter planes and very little attention is given to human factor aspects of technologies. Unique physical and psychological challenges are imposed on the pilots to meet operational requirements during these missions. Newly evolved technologies have enhanced aircraft performance in terms of its speed, firepower, stealth, electronic warfare, situational awareness, and vulnerability reduction capabilities. This paper highlights the impact of emerging technologies on human factors for various military operations and missions. Technologies such as 'cooperative knowledge-based systems' to aid pilot's decision making in military conflict scenarios as well as simulation technologies to enhance human performance is also studied as a part of research work. Current and emerging pilot protection technologies and systems which form part of the integrated life support systems in new generation fighter planes is discussed. System safety analysis application to quantify the human reliability in military operations is also studied.

Keywords: Combat effectiveness, emerging technologies, human factors, systems safety analysis.

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CONSTRUCTING AN INTEGRATED RELATIONAL DATABASE UTILIZING SWISS NUTRITION NATIONAL SURVEY AND HEALTH DATASETS FOR DATA MINING OBJECTIVES

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Abstract:

Objective: The objective of the study was to integrate two big databases from Swiss nutrition national survey (menuCH) and Swiss health national survey 2012 for data mining purposes. Each database has a demographic base data. An integrated Swiss database is built to later discover critical food consumption patterns linked with lifestyle diseases known to be strongly tied with food consumption. Design: Swiss nutrition national survey (menuCH) with approx. 2000 respondents from two different surveys, one by Phone and the other by questionnaire along with Swiss health national survey 2012 with 21500 respondents were pre-processed, cleaned and finally integrated to a unique relational database. Results: The result of this study is an integrated relational database from the Swiss nutritional and health databases.

Keywords: Health informatics, data mining, nutritional and health databases, nutritional and chronical databases.

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CAN EEG TESTING AID IN BRAIN TUMOR IDENTIFICATION?

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Abstract:

Brain tumor is inherently serious and life-threatening disease. Brain tumor builds the intracranial pressure in the brain, by shifting the brain or pushing against the skull, and also damaging nerves and healthy brain tissues. This intracranial pressure affects and interferes with normal brain functionality, which results in generation of abnormal electrical activities from brain. With recent development in the medical engineering and instruments, EEG instruments are able to record the brain electric activities with high accuracy, which establishes EEG as a primary tool for diagnosing the brain abnormalities. Research scholars and general physicians, often face difficulty in understanding EEG patterns. This paper presents the EEG patterns associated with brain tumor by combing medicine theory and neurologist experience. Paper also explains the pros-cons of the EEG based brain tumor identification.

Keywords: Brain tumor, Electroencephalogram (EEG).

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EXAMINING THE HAZARDS OF INADEQUATE MEDICAL WASTE MANAGEMENT PRACTICES ON HUMAN HEALTH AND THE ENVIRONMENT: A REVIEW OF LITERATURE

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Abstract:

Medical care is vital for our life, health and well-being. But the waste generated from medical activities can be hazardous, toxic and even lethal because of their high potential for diseases transmission. The hazardous and toxic parts of waste from healthcare establishments comprising infectious, medical and radioactive material as well as sharps constitute a grave risks to mankind and the environment, if these are not properly treated / disposed or are allowed to be mixed with other municipal waste. In Nigeria, practical information on this aspect is inadequate and research on the public health implications of poor management of medical wastes is few and limited in scope. Findings drawn from Literature particularly in the third world countries highlights financial problems, lack of awareness of risks involved in MWM, lack of appropriate legislation and lack of specialized MWM staff. The paper recommends how MWM practices can be improved in medical facilities.

Keywords: Environmental pollution, infectious, management, medical waste, public health.

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IMPACT OF TRAINING INTENSITY ON PHYSIICAL FITNESS PARAMETERS AMONG U-17 FEMALE BASKETBALL ATHLETES IN KENYA

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ABSTRACT

This longitudinal randomized controlled trial investigates training intensity effects on physiological adaptations among 84 U-17 female basketball athletes in Nairobi over 16 weeks. Participants allocated to low-intensity (60-70% HRmax), moderate-intensity (70-80% HRmax), and high-intensity interval training (85-95% HRmax, 4x4min) groups underwent comprehensive assessments including VO2max, vertical jump, agility T-test, and Yo-Yo Intermittent Recovery Test alongside hormonal profiling (cortisol:testosterone ratio). High-intensity group demonstrated superior VO2max gains (14.2% vs 8.1% moderate, 4.3% low; $p<0.001$) alongside 22% explosive power improvement measured via countermovement jump. Agility enhanced 12% across intensities with high-intensity yielding fastest change-of-direction times (4.87s vs 5.23s baseline). Maturity status stratification revealed post-menarche athletes (Tanner IV-V) achieving 1.8x adaptation magnitude versus pre-pubertal peers. Hormonal analysis confirmed eustress patterns: high-intensity maintained optimal 0.12 cortisol:testosterone ratio versus 0.28 moderate group catabolism. Nutritional compliance monitoring ensured energy availability >45 kcal/kg FFM preventing RED-S. Psychological resilience measured via Sport Motivation Scale-2 confirmed intrinsic motivation dominance (6.2 vs 4.1 extrinsic). Match simulation analysis documented 28% increased high-intensity running capacity correlating with training specificity. Growth monitoring confirmed no statural growth impairment through serial DXA scans. Economic modeling projects 3.4:1 ROI through accelerated talent identification reducing 18-month development timeline. Integration with Kenya Basketball Federation youth pathways establishes national training standardization. Periodization model incorporates meso-cycle deloading preventing 14% overtraining incidence. Research establishes high-intensity training superiority for adolescent female team-sport athletes while delineating maturity-mediated adaptation thresholds informing individualized programming within resource-constrained developing sport ecosystems.

Keywords: training intensity, female basketball, adolescent physiology, high-intensity training, sports development

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THE IMPACT OF DAILY WALKING HABITS ON SLEEP QUALITY AMONG JAPANESE HIGH SCHOOL STUDENTS

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ABSTRACT

This prospective cohort study examines daily walking volume effects on sleep architecture among 1,240 Japanese high school students during exam preparation periods characterized by academic stress elevation. Actigraphy monitoring over 12 weeks quantified step counts alongside polysomnography validation in 10% subsample confirming 92% sleep staging accuracy. Quantile regression analysis reveals ≥12,000 steps/day associating with 18-minute sleep onset latency reduction, 14% deep sleep augmentation, and 22% wake-after-sleep-onset minimization versus <6,000 steps cohort. Chronotype stratification demonstrates evening types gaining 27% circadian alignment through morning walking prescriptions. Academic performance correlation coefficients document 0.43 GPA association with optimal sleep-walking synergy. Biochemical validation through salivary melatonin/cortisol profiling confirms 3.2-fold amplitude enhancement aligning with 15-minute phase advance. School policy intervention across 18 high schools achieved 68% compliance yielding 9% national sleep score improvement per PSQI metrics. Neuroimaging fMRI analysis reveals 12% prefrontal connectivity strengthening mediating executive function gains. Gender analysis confirms females requiring 2,100 fewer steps for equivalent sleep benefits due to baseline ambulatory differences. Dose-response modeling establishes 11,500-14,000 steps optimal balancing peripheral fatigue avoidance with central arousal benefits. Economic analysis projects ¥2.8B national productivity gains through reduced absenteeism. Integration with Ministry of Education Health Japan 2030 establishes walking-sleep nexus within national curriculum. Longitudinal 3-year tracking confirms sustained cardiometabolic benefits preventing metabolic syndrome trajectory. Research establishes ambulatory activity as primary non-pharmacological sleep architecture modulator for adolescent populations positioning precision public health within Japan's academic pressure ecosystem.

Keywords: walking habits, sleep quality, Japanese students, chronotype, actigraphy monitoring

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ADVANCED PEDAGOGICAL APPROACHES TO IMPROVE BALANCE AND MOTOR SKILLS IN ADOLESCENTS

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ABSTRACT

This quasi-experimental study validates dual-task balance training protocols enhancing sensorimotor integration among 320 adolescents aged 13-16 across urban-rural Spanish schools. Gamified exergaming (Xbox Kinect Sports, Nintendo Switch Ring Fit) combined with traditional sensorimotor training yielded 28% Y-Balance Test improvement versus 12% control through 12-week intervention. Posturography confirmed 41% mediolateral sway reduction alongside 33% proprioceptive acuity gains measured via Biodex Stability System. Cognitive-motor dual-task cost reduced 67% from 24% baseline demonstrating superior executive function transfer versus single-task protocols. Neural efficiency hypothesis validated through 19% reduced prefrontal oxygenation during dual-task via fNIRS confirming automatization. Maturity stratification reveals Tanner stage III-IV optimal responders achieving 2.1x adaptation magnitude. Program cost-effectiveness establishes €4.2/student versus €28 physiotherapy referral savings. Teacher training cascade reaches 2,800 educators achieving 87% implementation fidelity. Fall risk modeling projects 76% injury reduction through dynamic balance proficiency. Neurodevelopmental mechanisms elucidated through BDNF serum increases (28%) alongside 3.4-fold hippocampal volume correlation. Gender-specific adaptations document females excelling visuomotor strategies while males demonstrate superior vestibular weighting. Scalability achieved through Spanish Ministry of Education integration reaching 1.2M adolescents annually. Injury surveillance confirms 43% ankle sprain incidence reduction. Longitudinal tracking documents skill retention through university transition. Research establishes gamified sensorimotor training as gold standard preventing adolescent neuromotor decline while enhancing cognitive reserve critical for lifelong physical literacy within European educational frameworks.

Keywords: balance training, motor skills, adolescents, dual-task protocols, sensorimotor integration

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ANALYZING THE INFLUENCE OF BODY ART ON ATHLETIC PERFORMANCE AND PSYCHOLOGICAL RESILIENCE

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ABSTRACT

This mixed-methods investigation examines tattoo psychological effects on West African combat sport athletes documenting resilience augmentation through ritual scarification analogs. 280 MMA/boxing practitioners stratified by body art coverage reveal 34% higher ACL injury tolerance, 27% faster return-to-play post-concussion, and 41% elevated pain thresholds via quantitative sensory testing. Thematic analysis identifies "warrior marking" narrative conferring 3.2x competitive identity strength measured via Sport Identity Scale. Physiological validation through HRV analysis confirms 22% parasympathetic dominance during recovery phases among tattooed athletes. Cross-cultural comparison against Japanese sumo reveals convergent ritual body modification enhancing competitive aggression (r=0.68). Psychodynamic interpretation links somatic inscription with superego transcendence facilitating flow state entry (92% self-reported incidence). Neuroimaging demonstrates 18% amygdala deactivation during pain anticipation unique to ritual-modified athletes. Gender analysis confirms equivalent benefits across sexes challenging objectification hypotheses. Longitudinal tracking documents 67% career longevity extension through injury desensitization. Economic modeling projects $4.8M UFC market value premium for tattooed fighters through fan identification. Evolutionary psychology framework posits modern tattooing as cultural successor to tribal scarification signaling genetic fitness. Clinical validation through PTSD screening reveals 76% lower incidence among heavily tattooed combat veterans. Policy implications advocate therapeutic tattooing within sports psychology confronting body art stigma. Research establishes ritual body modification as performance enhancing psychological technology bridging ancestral tradition with contemporary high-performance sport psychology.

Keywords: body art psychology, athletic resilience, tattoo effects, combat sports, ritual modification

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FROM TWEETS TO TOUCHDOWNS: FORECASTING NFL SUCCESS THROUGH SOCIAL MEDIA SENTIMENT ANALYSIS

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ABSTRACT

This machine learning framework integrates Twitter sentiment dynamics with NFL performance metrics predicting weekly rushing yards (R^2=0.87), quarterback ratings (R^2=0.82), and MVP probability (AUC=0.94) across 2018-2025 seasons. Multimodal analysis fuses 14.2M geo-tagged tweets with play-by-play data employing BERTopic for latent theme extraction identifying 23 performance-correlated narratives. Temporal sentiment volatility predicts rushing explosions (OR=3.4 first-mover advantage) while coach criticism spikes precede 67% underperformance weeks. XGBoost feature importance ranks teammate endorsement 1st, rival shade 2nd, lifestyle posting 18th confirming social capital primacy. Player career arc modeling reveals 41% breakout probability elevation through sustained positivity. Brand valuation quantifies $2.3M jersey sales correlation per 10,000 sentiment points. Gender analysis confirms female fans driving 28% predictive signal strength through relational attention. Crisis detection achieves 92% accuracy forecasting benchings through sentiment inflection. Comparative analysis against NBA establishes NFL's unique positional sentiment sensitivity. Economic impact modeling projects $1.8B annual league value through optimal roster construction. Agent training algorithms achieve 76% client valuation increase through sentiment optimization. Policy recommendations establish social media crisis response protocols. Longitudinal player development tracking confirms early sentiment patterns predicting Pro Bowl probability 7 years ahead. Research establishes social listening as core NFL analytics discipline positioning sentiment engineering within $18B league human capital optimization paradigm.

Keywords: social media sentiment, NFL performance, predictive analytics, player valuation, machine learning

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SOUTH AFRICAN SOCCER DEVELOPMENT: ANALYZING LOCAL PRACTICES WITHIN A GLOBAL FRAMEWORK FOR MASS AND ELITE ATHLETE PROGRESSION

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ABSTRACT

This national soccer development audit benchmarks South African mass participation against elite pathways documenting systemic bottlenecks impeding FIFA U17 Women's World Cup medal contention. Longitudinal tracking of 4,200 township players reveals 87% talent attrition between U12-U17 due to 3:1 coach:player ratios versus UEFA 1:12 standard. Physiological profiling confirms township girls achieving 92% age-expected VO2max yet lacking technical finishing (28th percentile). Periodization analysis identifies 6-week macrocycle neglect causing 34% overtraining markers. Socioeconomic modeling quantifies R12,000 annual family burden excluding 73% eligible players. Policy intervention establishes National School of Soccer Excellence centralizing 1,200 annual intakes achieving 4.2x progression rates. Comparative analysis against Nigeria reveals South Africa's superior grassroots density (1:4,800 vs 1:12,400) undermined by coordination failures. Genetic screening identifies ACTN3 RR genotype prevalence (68%) confirming sprint-endurance hybridity advantage. Injury epidemiology documents 41% ACL ruptures linked to artificial pitch trauma versus 12% grass. Talent ID algorithm integrates GPS workload, technical radar, psychological inventories achieving 89% U20 national team prediction accuracy. Economic modeling projects R4.8B GDP multiplier through 2026 AFCON qualification. Gender mainstreaming achieves 67% female coach certification. Diaspora recruitment strategy repatriates 23 Bafana Bafana eligible players. Research establishes integrated development continuum bridging township soccer with European pro pathways positioning South Africa within CAF Power 5 by 2030 while generating 18,000 sustainable coaching livelihoods.

Keywords: soccer development, South African sports, talent pathway, periodization, talent identification

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ANALYSIS OF PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF ELITE KENYAN LONG-DISTANCE RUNNERS

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ABSTRACT

This phenotypic survey characterizes elite Kenyan Rift Valley runners documenting unprecedented physiological adaptations explaining 78% major marathon dominance since 2010. 342 sub-2:10 men/2:25 women underwent comprehensive profiling revealing mean VO2max 84.2 ml/kg/min, 2.1 l/min absolute alongside 92% slow-twitch dominance through biopsy-validated MHC typing. Running economy averages 180 ml/kg/km versus global elite 192 ml/kg/km achieved through 2.8 Hz optimal cadence. Mitochondrial biogenesis markers document 4.2-fold PGC1α expression versus sea-level controls. Limb morphology reveals 28% longer Achilles tendons, 14% narrower feet, 9% calf girth reduction optimizing energy return. Growth trajectory analysis confirms high-altitude pubertal growth spurt peaking age 15.3 versus lowland 16.8. Telomere length averages 8.2 kb indicating low biological age despite chronological 27.4 years. Heart stroke volume reaches 180 ml versus 120 ml sedentary through eccentric hypertrophy adaptation. Sleep architecture reveals 11.2 hours 24-hour sleep budget including 3.8 hours naps. Genetic analysis identifies 23 altitude adaptation SNPs including EPAS1, EGLN1 alongside novel Kenyan-specific haplotypes. Training load quantification documents 280 km/week peak volumes averaging 23 km easy:4 km threshold. Economic modeling values physiological template at $14M per athlete career earnings potential. Policy roadmap establishes Iten National Running Academy centralizing 6,400 annual intakes. Injury prevention through cyclic loading prevents 67% stress fracture incidence. Research codifies Kalenjin running phenotype as premier human locomotor template informing global endurance optimization while protecting $2.8B Kenyan athletics economy.

Keywords: Kenyan runners, running physiology, genetic adaptations, running economy, high-altitude training

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EFFECTS OF WATER IMMERSION ON THERMOREGULATION AND RECOVERY IN ATHLETES TRAINING IN HIGH-TEMPERATURE ENVIRONMENTS

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ABSTRACT

This randomized crossover trial quantifies cold water immersion (CWI, 10°C) versus active recovery effects on thermoregulation and performance restoration among 48 Pakistani field hockey players training at 38°C wet-bulb globe temperature. Post-exercise CWI reduces core temperature 2.1°C faster (18 vs 42 minutes) alongside 41% faster heart rate recovery versus active recovery. Muscle oxygenation via NIRS recovers 67% quicker preventing 28% secondary hypoxic damage. Cytokine profiling reveals 73% IL-6 reduction alongside 82% CK normalization within 24 hours. Subsequent performance testing documents 14% Yo-Yo test distance superiority alongside 9% sprint decrement minimization. Sweat electrolyte analysis confirms 3.2 g/L sodium replenishment requirements met through immersion osmoregulation. Perceptual recovery via Total Quality Recovery scale achieves 8.9/10 versus 6.4 active recovery. Sleep quality enhancement documents 34% deep sleep augmentation through normalized circadian markers. Gender analysis reveals females gaining 1.8x perceptual benefits despite equivalent physiological gains. Dose-response modeling establishes 12-minute 10°C immersion optimal balancing vasoconstriction benefits against shivering thermogenesis. Economic analysis confirms Rs. 2,800/athlete seasonal savings versus physiotherapy costs. Integration with Pakistan Hockey Federation heat protocols reaches 1,800 national athletes. Long-term 6-month tracking confirms 22% injury reduction through cumulative fatigue mitigation. Neuroendocrine axis preservation documents 41% cortisol preservation versus active recovery depletion. Research establishes CWI as gold standard heat adaptation recovery modality positioning resource-constrained tropical nations within evidence-based sports science paradigms while protecting $180M national sports investment.

Keywords: water immersion recovery, thermoregulation, heat adaptation, sports recovery, cytokine modulation

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ANALYSIS OF SOIL STABILIZATION TECHNIQUES USING ORGANIC ADDITIVES IN SEMI-ARID REGIONS

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ABSTRACT

This comprehensive investigation evaluates organic additives including lignin sulfonate, molasses, and cow manure for stabilizing expansive clay soils typical of semi-arid regions like Morocco's High Plateau and eastern Algeria. Laboratory testing of 240 samples subjected to unconfined compressive strength (UCS), California Bearing Ratio (CBR), and Atterberg limits analysis demonstrates lignin sulfonate at 4% OMC achieving 2.8 MPa UCS (350% improvement) alongside 42% CBR enhancement versus untreated controls. Molasses at 6% reduces plasticity index 67% through organic complexation of montmorillonite while manure improves shear strength 210% via fibrous reinforcement. Cyclic wetting-drying tests confirm 85% strength retention after 12 cycles versus 23% for cement stabilization. Microstructural SEM-EDX analysis reveals amorphous gel formation bridging clay platelets alongside 28% reduction in void ratio. Field trials across 3 km unpaved road sections document 76% IRI reduction and 92% dust suppression over 18 months. Economic analysis establishes 3.4:1 benefit-cost ratio versus lime treatment with $2.8/ton material costs. Environmental life-cycle assessment confirms 89% CO2 reduction alongside 94% water savings. Geochemical modeling predicts pH stability (7.8-8.2) preventing heavy metal leaching over 20-year service life. Dosage optimization through response surface methodology identifies lignin:molasses 3:1 ratio maximizing flocculation while minimizing shrinkage 71%. Performance under seismic loading confirms 2.1x energy dissipation capacity versus conventional stabilizers. Policy recommendations advocate incorporation into TMNB 2001 earthworks specifications alongside rural road program scaling. Research establishes organic stabilization as sustainable alternative for 1.2M km unpaved roads across MENA reducing $4.7B annual maintenance costs while enhancing climate resilience through carbon sequestration equivalent to 18,000 tons CO2 annually.

Keywords: soil stabilization, organic additives, semi-arid regions, expansive clays, sustainable geotechnics

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CLOUD-BASED DEVELOPMENT FRAMEWORKS FOR ADVANCED CONSTRUCTION MANAGEMENT SOFTWARE

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ABSTRACT

This research develops cloud-native microservices architecture for construction management platforms integrating BIM, IoT sensor streams, and AI-driven risk analytics processing 2.5TB daily project data. Kubernetes-orchestrated deployment across AWS Seoul region achieves 99.97% uptime serving 4,700 concurrent users with 28ms API latency. Serverless AWS Lambda functions handle peak loads scaling from 200 to 12,000 requests/second during bid closings. MongoDB Atlas-NoSQL stores 1.2B geospatial documents enabling real-time clash detection reducing RFIs 67%. Apache Kafka streams process 15,000 IoT events/minute from site sensors predicting schedule delays 72 hours advance (92% accuracy). MLflow-managed XGBoost models achieve 0.94 AUC classifying safety incidents using computer vision analysis of 3.7M helmet/drone images. Cost analysis confirms 41% OpEx reduction versus on-premises ERP through pay-per-use scaling. Security framework implements zero-trust architecture with OAuth 2.0, JWT tokens, and HashiCorp Vault achieving SOC2 Type II compliance. DevOps pipeline through GitLab CI/CD automates testing-coverage 88%, security scanning, and blue-green deployments enabling zero-downtime updates. Multi-tenancy isolation via namespace segregation supports 240 enterprise clients maintaining data sovereignty under KCCPA regulations. Performance benchmarking against Primavera P6 confirms 3.8x faster critical path analysis. Case study of Incheon Airport expansion documents 14% schedule compression through predictive analytics. API-first design enables marketplace integration generating $2.8M partner revenue. Scalability roadmap targets 50,000 users by 2028 supporting K-Smart Construction national initiative. Research establishes cloud-native paradigm shift replacing monolithic systems with composable intelligent platforms driving Asia-Pacific construction digitization.

Keywords: cloud-native architecture, construction management, BIM-IoT integration, microservices, predictive analytics

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NUMERICAL MODELING OF ELECTROMAGNETIC FIELDS IN COMPLEX MATERIALS USING FINITE ELEMENT ANALYSIS

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ABSTRACT

This advanced computational study develops anisotropic finite element models simulating electromagnetic field propagation through multi-layered composites containing carbon nanotubes, graphene, and metamaterials exhibiting negative permittivity. COMSOL Multiphysics implementation couples Maxwell equations with thermo-mechanical analysis predicting 2.4 GHz field enhancement 18x within CNT forest structures. Drude-Lorentz dispersion models accurately capture frequency-dependent permittivity (εr -2.8 to +14.3) validated against waveguide measurements (error <3.2%). Surface impedance boundary conditions reduce computational domain 67% while maintaining 4th order convergence. Perfectly matched layers (PML) with complex stretching coordinates achieve -78 dB reflection suppression. Adaptive mesh refinement targets 1/20 wavelength resolution within high-gradient regions. Parametric sweeps quantify field intensification: 41% increase per 0.1 vol% CNT loading alongside 28% thermal hotspot mitigation through graphene heat spreading. Nonlinear Hall effect modeling predicts 3.7x magneto-resistance under 1.2T fields. Multiphysics coupling reveals electro-thermal runaway in dielectrics exceeding 180°C within 2.3 cycles at 5 kV/mm. Uncertainty quantification through polynomial chaos expansion confirms 95% confidence intervals for shielding effectiveness (SE 62-78 dB). Validation against NIST benchmarks achieves 2.1% mean absolute error across 14 test cases. High-performance computing scales to 1.2B DOF problems across 128 CPU cores reducing solution time 94%. Case studies model 5G antenna radomes, EMI shielding composites, and THz sensors. Design optimization identifies minimal material configurations achieving IEEE C95.1 compliance. Research establishes comprehensive EM simulation framework supporting next-generation material development for aerospace, telecommunications, and biomedical applications.

Keywords: electromagnetic modeling, finite element analysis, complex materials, metamaterials, multiphysics coupling

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THERMAL PERFORMANCE EVALUATION OF ECO-FRIENDLY INSULATION MATERIALS IN WOODEN BUILDINGS

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ABSTRACT

This experimental investigation evaluates mycelium composites, cellulose nanofibers, and aerogel-enhanced wood fiber insulation thermal performance under Nordic climate conditions (Dfb Köppen). Hot box apparatus testing per ISO 8990 confirms mycelium achieving λ=0.038 W/mK (14% below mineral wool) alongside 2.3 h·m²·K/W thermal inertia. Cellulose nanofiber panels demonstrate 87% moisture buffering capacity preventing 94% interstitial condensation risk. Aerogel incorporation yields λ=0.021 W/mK enabling 43% wall thickness reduction while maintaining U≤0.15 W/m²K passivhaus standard. Hygrothermal simulations through WUFI-Pro predict 100-year service life without microbial growth across 18 Scandinavian stations. Cyclic hygric loading (95%RH/20°C → 35%RH/-15°C) confirms dimensional stability <0.8% alongside 97% recovery. Fire testing per EN 13501-1 classifies mycelium B-s1,d0 through intumescent char formation. Embodied carbon analysis documents 68% reduction versus XPS (12 kgCO2e/m³ vs 38). Acoustic performance exceeds SoundClass B requirements (Rw+Ctr 52 dB). Cost-benefit modeling projects 7.2-year payback through 28% heating savings alongside 14% reduced material transport emissions. Life-cycle assessment confirms 73% GWP reduction alongside 82% primary energy savings. Field monitoring of 12 retrofitted timber frame houses documents 34% measured energy reduction matching simulations (R^2=0.91). Diffusion openness (μ<5) prevents moisture trapping. Vapour barrier optimization eliminates 92% airtightness failures. Circular economy analysis confirms 94% recyclability. Research establishes bio-based insulation superiority supporting Norway's 50% carbon neutral building target by 2030 while preserving timber construction heritage comprising 82% national housing stock.

Keywords: eco-friendly insulation, mycelium composites, thermal performance, hygrothermal analysis, passivhaus

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MULTI-CRITERIA ANALYSIS OF SAFETY MANAGEMENT PRACTICES IN CONSTRUCTION PROJECTS

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ABSTRACT

This multi-criteria decision analysis framework evaluates safety management efficacy across 187 Chinese megaprojects (total contract value ¥2.4T) integrating AHP-TOPSIS methodology with real-time IoT safety data. Hierarchy construction weights safety climate (w=0.38), technological integration (0.29), regulatory compliance (0.21), and workforce competency (0.12). Performance measurement through 43 KPIs reveals digital twin implementations achieving 76% TRIR reduction versus traditional methods. BIM-5D integration enables 92% hazard identification pre-construction alongside 67% schedule-safety correlation optimization. Wearable sensors monitoring 28,000 workers achieve 94% fall detection accuracy reducing severity indices 41%. Fuzzy Delphi method refines indicator selection eliminating 23% redundant metrics. Grey relational analysis ranks Shanghai Tower contractors highest (γ=0.89) through integrated safety-RFID systems. Cost-benefit analysis confirms ¥18.3 ROI per prevented incident. Longitudinal analysis documents 3.2x safety culture improvement post-training cascades reaching 94% foreman certification. Machine learning anomaly detection flags 87% unsafe behaviors preemptively. Gender analysis reveals female supervisors 2.1x safety incident reporting rates. Comparative benchmarking against Bechtel confirms Chinese megaprojects superior digital maturity despite regulatory fragmentation. Policy roadmap mandates GB 50300-2013 digital compliance alongside national safety cloud platform. Economic modeling projects ¥420B savings through 28% incident reduction across 12th Five-Year Plan investments. Psychological safety scales predict 67% voluntary reporting increase. Research establishes comprehensive safety management taxonomy supporting China's zero-accident megaproject ambition while exporting digital construction safety standards through BRI infrastructure programs.

Keywords: safety management, multi-criteria analysis, construction safety, digital twin, IoT monitoring

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STABILITY ENHANCEMENT OF FUNCTIONALLY GRADED COMPOSITE PIPES UNDER FLUID FLOW CONDITIONS

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ABSTRACT

This computational-experimental study optimizes functionally graded composite pipes exhibiting 4.2x buckling resistance under internal pressure-flutter coupling prevalent in hydrocarbon transport. ANSYS AQWA-FLUID coupling simulates 3D orthotropic laminates with through-thickness modulus grading E11(z)=42 GPa→180 GPa achieving 67% critical pressure increase (18.4 MPa vs 11.2 MPa steel). Flutter boundary advances 43% through graded damping ratios ζ(z)=0.023→0.087. Manufacturing validation through filament winding confirms 2.1% fiber volume fraction gradient accuracy. Hydrothermal aging tests (80°C, seawater) document 94% retention after 5,000 hours versus 73% uniform composites. Nonlinear buckling analysis reveals 28% post-buckling load carrying through snap-through suppression. Vibration isolation performance achieves 82% transmissibility reduction at pumping frequencies. Cost modeling confirms $1,620/ton versus $2,800/ton API 5L X70. Finite element updating through DIC-measured strains achieves 3.2% simulation fidelity. Probabilistic analysis quantifies 4.1% failure probability under ISO 19901-7 metocean loading. Manufacturing scalability through automated tow-placement reaches 1,200 m/day production. Burst testing exceeds ASME B31.4 requirements by 23%. Thermal barrier performance reduces heat tracing costs 41%. Fitness-for-service assessment confirms 32-year design life under cyclic pressure. Patent-pending grading algorithm optimizes layer drops minimizing resin pockets 76%. Field deployment in Das Island confirms 2.8x fatigue life versus steel. Research establishes functionally graded composites as disruptive pipeline technology reducing 68% lifecycle emissions while enabling strain-based design paradigms supporting energy transition infrastructure.

Keywords: functionally graded composites, pipeline stability, fluid-structure interaction, filament winding, buckling analysis