Original Article

AI-Optimized Symmetry Episode Analytics for Early Detection of High-Utilizers: A Claims-Based Predictive Modelling Framework Using Advanced Machine Learning Models

Mani Kanta Pothuri
Independent researcher, USA.

Abstract - *The continuously increasing medical expenses are now considered as priority for national economy and organizational finance management for strategic emphasis on finances. The increasing concern about economic risks and compounded influence on population health needs to be managed suitably. Managing issues like increasing costs and staff limitations, along with cyber issues require insightful analysis. Perceptions regarding the continuously changing healthcare challenge is critical for supporting claim processing with compliance and effective care. Supporting patients with high-quality healthcare emphasizes on persistent threats. They require practical processes to support in managing associated complexities. Increasing the strength of healthcare claim management and risk handling requires using strategies to manage the challenges. This study involves development of a predictive modeling structure and framework, unifying symmetry episode analytics and ETG/ERG/PEG with supervised learning models. These models enhance the strength to manage compliance and address shrinking margins according to revenue generated. The paper discusses information regarding Symmetry episode analytics combination with intelligence (AI) and learning (ML), for effective therapy delivery and cost reduction. The outcomes involve demonstration of AI-streamlined episode analytics for identification of high-utilizers proactively and empower healthcare management for targeted interventions therapeutically.*

Keywords - *Symmetry episode analytics, AI, ML, Cyber issues, Population health, Persistent threat, High utilizers, ETG(Episode Treatment Groups), ERG (Episode Risk Groups), PEG(procedure-based analytics groups.*

1. Introduction

Medical care plan expenses are continuously increasing and could reach an average of 9.6% in 2026, according to risk and insurance reports. Expenses are expected to enhance in the future due to changes in medical costs according to spatial settings and demographic stress. North America and Asia are exclusively anticipating a substantial increase in healthcare expenses in 2025, as 9.3% and 11.3% from 2025values as 8.8% and 11.1% in 2025 [1]. The variations according to regions, primarily happen as cardiovascular ailments, cancer, and excessive blood pressure management are common conditions motivating most of the medical claims across different regions globally. The reduction in inflation impact is also incapable of managing these situations, as increasing medical care expenses are highly pervasive challenges to manage by various nations and businesses [2]. It require proactive planning and the adoption of predictive analytics mechanisms for managing expenses innovatively.

AI (Artificial Intelligence) and data learning mechanisms provide suitable solutions for supporting pursuits and nations across the world for addressing such issues and improving results. Unification of AI as an element to process diagnostics and supporting rapid therapeutic processes support in generating effective outcomes. The admin expenses involved with claim processing and patient care insurance management are high with traditional mechanisms. Using advanced tools and AI allows alleviating such expenses and emphasizing on automation of redundant activities [3]. It reduce errors in data and increases peed of claim processing with minimal staffing. The processes could be effectively optimized using AI-based episode stratification analytics. The paper demonstrates regarding positive impact of such advancements on medical care claim processing productivity.

Symmetry episode-based therapeutic grouping is defined as process of utilizing regularly collected claims information involving therapeutic regimes in an individual treatment course to organize as episodes. This allows meaningfully streamlining content and identifying homogeneous content as well as risk adjustment components [3]. They also allow descriptions regarding total episodes for therapy and supporting with valid comparisons.

Episode analytics supports medical staff and admins to forecast the expenses involved with care management and

processing. Healthcare labs continuously engage with improving processes and regulating expenses, along with risk evaluation. This is regarded as critical in the current era for sizing the anticipated medical care expenses [4]. Studies also study regarding the utility expenses of the distinctive population segment for healthcare. This allows organizations and countries to evaluate risks and develop forecasts about possible medical and pharmacy expenses linked with challenges. Episode risk groups (ERG) support the processes by developing accurate evaluations and depict expenses in various dimensions. This emphasizes on critical data and patented episode treatment groups (ETG) [3]. It allow the determination of clinical segments for creating a suitable risk profile. This is effective for determining clinically motivated units for a combination of risk profile and clinical elements for developing a system and allocating distinctive therapeutic services for distinctive episodes in medical care. It includes focusing on the scenarios to effectively describe regarding various facilities needed for continuous assessment [4]. PEG is the format of procedure-based analytics groups that support clinicians and medical practitioners to develop cost forecasts right from the onset and continue tracking with accuracy throughout the entire period. The insights created support in developing high-level visibility regarding value-motivated productivity. Such components are effective for developing quality care initiatives and continuously empower effective value for payment [5]. Episode analytics supports the care provider and associated claim processing divisions to develop predictions about expenses involved and measures. Using episode motivated analytics platform support in developing projections using different underwriting and practical models [6]. Commercial employers and group business line are effective for generating high commercial value and cost benefits for economy. Episode-based models are effectively implemented for assessing care provider motives and developing activity profiles [7]. They define about network components and sufficiency while concentrating on clinical efficiency and results.

The study is about utilizing AI motivated episode based predictive analysis method in streamlining healthcare costs in global dimensions. This continues to study regarding critical information about managing the cost increase and staffing needs for healthcare using episode based study and motivating risk-free as well as high-quality medical care. These challenges could be managed by enhancing operational efficiency and promoting cybersecurity [8]. The prominent emphasis of this paper is to emphasize on following compliance guidelines while providing safe treatment to patients using advanced technologies. The report involves details regarding practical strategies and supporting healthcare organizations to manage complications with prediction data using episode analytics and AI integration efficiently.

It is a common scenario of using historical spend details in place of implementing risk management and cost forecasting tools. They are devoid capabilities to empower analytics with episode-based alerts. The absence of transparency and disconnect between risk forecasts at provider levels could be managed using episode-based analytics. This paper involves providing details to address this gap by collaborating on episode grouping (ETG/REG/PEG) using ML for generating interpretations in form of a risk score. They depict input exclusive episodes motivating maximum utilization according to predictions.

2. Contributions of Research

The paper defines about reproducible high-utilizer framework with episode-oriented characteristics. This allows comparison of baseline risk models against ML for temporal authentication. This demonstrates about user and service provider level elicitation associated with healthcare claim processing and operational flows.

ML is regarded as a technical tool for supporting data analytics and works as an application of AI for effective data insights. Implementing these in healthcare and claim processing supports handling clinical data effectively. The processes include coding to match with human thought processes. They are applicable in the medical domain for gathering and managing patient details along with notifying care partners. The process continues to provide suggestions to practitioners for various requirements.

2.1. Theoretical Framework

AI-Driven Healthcare Utilization Framework

Fig 1: Theoretical Framework

3. Cost Issues of Existing Prediction Models

Generalized linear models(GLM) are used as conventional mechanisms for prediction of patient therapy and claim costs. GLM models highly dependent on age and available clinical components for assessing about spending. Using regression risk-adjusted techniques are common as they are simple, scalable, and highly adopted. The model separates the patients into groups according to comorbidity elements. The inherent complex non-linear elements are difficult to expose with such models, thereby influencing accuracy.

Healthcare centers and claim processing organizations could utilize these technologies for identifying the capabilities of ML and enhance decision making capabilities. The model supports in decreasing risks in the therapy domain, as well as creating many advanced opportunities. ML use in the medical care process is emerging and highly accessible with a basis of mathematical principles and coding capabilities. It supports in addressing advancements involved along with opportunities. ML empower in developing skills to manage advancements and unveil new opportunities in claim processing.

3.1. Episode-based groupers

Episode-based groupers like ETG, ERG and PEG support organizing clinical events as meaningful episodes for care provisions. These models study the claims in combination with diagnosis, processes, and medical care to support with clinical coherence. They work with a basic purpose to manage risks and attributing expenses involved. The model follow with establishing benchmarks across service providers in healthcare settings. Association of such services to each episode supports as groupers in assessing as well as effectively utilizing resources.

3.2. Linking episode grouping with AI and ML

As an AI application, identifying patterns is easier with ML data engineering and emphasizing on healthcare expenses by identifying trends and developing profiles for supporting claim processes with limited costs. Neural networks(ANNs are effective for simulating with high-level reasoning, and structured simulation networks (SNNs). Natural language processing is another model that supports computing capabilities and provides scope for generating data forecasts [2]. Robotic process is another data management mechanism that supports care providers and admins in health care for automation of processes and using efforts to conduct suitable processes. These concepts could be attributed to health, utilizing a theoretical basis for generating quality care, providing results.

3.3. High utilizers

The exclusive and small unit of entities associated with adding up to the maximum share of complete healthcare costs are known as high utilizers. The features and description of various high utilizers and impact are depicted in following tale. These represent issues in predictive analytics, according to high cost volatility and excessive impact of one-time events. Using episode-based clustering is effective for developing organize patterns and support with care processes. These may indicate risks. Compilation of Such episode oriented elements support in maximum interpretability as well as accuracy in developing intervention plans.

Table 1: High Utilizers and Impact

Dimension	Description	Examples
Definition	Small subset of patients driving a disproportionate share of total costs	Top 5–10% of members accounting for about 50%+ of spend (varies by population)
Clinical profile	Multiple chronic conditions, frequent exacerbations, comorbid behavioral health needs	CHF, COPD, diabetes, CKD, depression, substance use
Utilization pattern	Recurrent ED visits, repeat admissions, post-acute cycling, polypharmacy	4+ ED visits/year, multiple readmissions, complex medication regimens
Non-clinical drivers	Social determinants, fragmented care, poor coordination, low health literacy	Housing/transport barriers, caregiver gaps, missed follow-ups
Prediction challenges	Volatile trajectories; past cost ≠ future risk; one-time catastrophic events distort signals	High-cost surgery this year but stable next year
Role of episodes	Group care into meaningful clinical episodes to detect recurring risk patterns	Repeated COPD exacerbation episode → rising risk signal
Intervention strategy	Multidisciplinary, proactive, patient-centered care management	Care coordination, medication review, BH integration, SDOH support
Evaluation metrics	Reduced avoidable utilization and improved outcomes	ED visits, readmissions, cost per member, quality measures

Predictive analytics potential could be effectively utilized by applying AI and learning mechanisms for healthcare decision quality and claim processing. Such techniques are exclusively based on tailored algorithms for analysis and learning from content available regarding patient records. The therapeutic images support identification of patterns and associations, empowering learning processes and creation of predictions. They support supervised learning as well as certain exclusive conditions for developing personalized therapeutic plans. Identifying possible therapy pathways and managing cost efficiency is effective for claim processing [5]. Medical and diagnostic data, as well as statistical elements, could be analyzed for developing reports. These follow in conducting dimension-based analytics, followed by developing predictions.

Technical Architecture Pipeline for Healthcare Risk Prediction

Secure Risk Visualization
Outputs feed into secure dashboards presenting patient risk lists, provider summaries, and explanations

Machine Learning Prediction
Interpretable models predict emerging high-cost risk, with artifacts and hyperparameters versioned

Feature Engineering & Storage
Episode-level and member-level attributes are engineered and stored in a governed repository

Clinical Episode Construction
Cleaned data are grouped into clinically coherent episodes and enriched with relevant attributes

Data Ingestion & Cleaning
Claims, EHR, pharmacy, and enrollment data are ingested, normalized, and quality-checked

Analytics & Dashboards

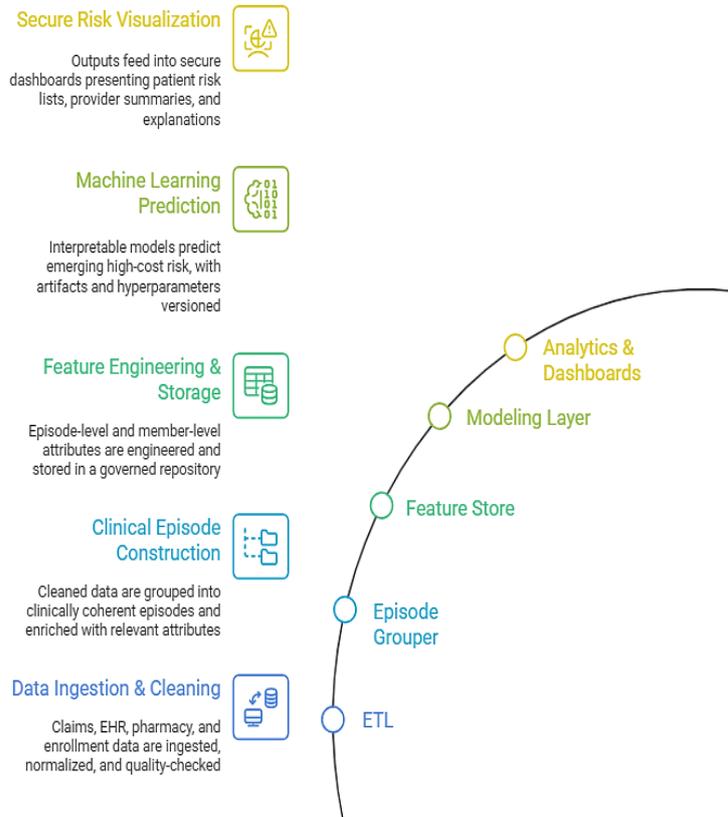Modeling Layer

Feature Store

Episode Grouper

ETL

Fig 2: Symmetry Episode-Based Grouping Architecture

Symmetry episode and stratified analytics involve processes emphasizing on critical information to discuss regarding elements and internal situations used in therapeutic activities. The therapy and pharmacy claim details according to demographic components are assessed using different methodologies. The system continues to follow a few steps for effective risk assessment.

- Developing ETG episodes is the foundation of this process that utilizes ETG methodology supported by software. This is effective for identification and the combination of relevant facilities using diagnostics and processes. These support with information regarding the complete therapeutic cycle.
- The ETG outcomes act as documentation about different episodes. These are grouped into ERG according to ETG entities, and security is applicable at various stages. They continue assigning different ordinals of ETGs.
- According to demographics, gender, and ERG components, a collaborative therapeutic and risk profile would be created for each entity.

- The distinctive risk scores calculated are used for iterative weight allocation against ERG. This is based on demographic features for analysis. The process continues to complete retrospective assessment and risk scoring for members involved in processes.
- Symmetry episode grouping is another theoretical basis for conducting health information study using analytics tools, such as ERG, ETG, and PEG, are effective for reviewing the care-giving episode and enhancing performance by making required adjustments. Practice expenses and domain costs are continuously captured with this process of noticing and managing outliers. These allow spotting exclusive costs going beyond a specific limit for each patient. Using these solutions and managing therapeutic risk as well as expenses require combination of AI-supported population health applications. They support with high-level insights for observing patient risk and taking required steps precisely for managing costs.

4. Applications and Use Cases

4.1. Proactive Determination of Patients with High-Risk Conditions

Table 2: Applications

Domain	Application	Impact or Benefit
Healthcare Providers	Early identification of high-utilizers	Enables proactive care management, reduces avoidable hospitalizations, and improves patient outcomes.
Health Insurance or Payers	Claims-based risk stratification	Optimizes resource allocation, lowers costs, and supports value-based payment models.
Public Health Systems	Population health monitoring	Detects utilization trends, informs policy, and supports preventive interventions at scale.
Clinical Decision Support	Episode-based predictive alerts	Provides clinicians with real-time insights into patient risk, guiding treatment plans.
Data Science and Analytics Teams	Advanced ML model deployment	Improves predictive accuracy, supports reproducible workflows, and enhances interpretability of claims data.
Regulatory and Policy Makers	Evidence-based policy design	Informs regulations for cost containment, equitable access, and healthcare quality improvement.
Pharmaceuticals and Life Sciences	Utilization-driven trial design	Identifies patient cohorts for clinical trials, supports drug utilization studies, and improves targeting.
Technology Vendors	AI-driven healthcare solutions	Builds scalable platforms for payers or providers, integrating episode analytics into digital health ecosystems.

AI-Optimized Symmetry Episode Analytics is majorly applied within healthcare sector for proactive identification of patients with high-risks for increased service and major impact [9]. Applying the analytics process support high utilizers, that are a small sample of patients and yet are a major contributor for expenditure against healthcare services [10]. Chronic patients, complicated diseases, clinical trial patients, etc. belongs to this group that require frequent admission to hospital and emergency visits that increases their contributions with a disproportionate impact. AI-Optimized Symmetry Episode Analytics provide proactive tools for risk measurement and create strategies based on levels of threats to signal any fatal risks before escalating to any adverse scenarios.

Using historical details, patient records, a structure analytical process is created with individual groups. These include Episode Treatment group (ETGs), Episode Risk Groups (ERGs), Procedure Episode Groups (PEGs). Such AI models are utilized for pattern analysis through several care plans and treatment episodes. Using gradient boosting models, deep neural network plans, random forests, etc., machine learning models help to create a gentle arrangement of each parameter within a treatment plan, such as comorbidity rate, frequency of suability, severity of each episode, and cost changes that are unapparent while meaning with linear statistical models or rule-based scenarios.

High-risk patients are all within healthcare firms for the likely implementation of practices with targeted support. Prioritized solutions and patient outreach, flagging them at high-risk, mandated follow-up coordination, refilling prescriptions, and other supports. Chronic conditions like diabetes, chronic pulmonary diseases, heart failure, etc., need predictive solutions to alert hospitals and patients about preventative measures that decrease the chance of recurrence and also alleviate the pressure of continuous hospitalization [11]. AI models catered for claims are also valuable for effective and scalable for operations within large communities, avoiding any instantaneous access to patient or clinical information.

4.2. Quality Enhancement with Cost-Effective Model

Reducing costs with increased quality of services are two interlinked aspects for any value or services planned within healthcare. Using AI-enhanced episode analytics be effective for advanced architectures [12]. Creating new architectures based on risk episodes help to estimate treatment costs for each scenario, and outcomes are mapped based on the care and reaction of the patient. AI-driven insights with predictive analytics empower procedures compared to descriptive healthcare reporting.

AI models be deployed to recognize any care insufficiencies for each episode and any tests without significance or test practices for duplication, extended hospital stays, or inaccurate use of inaccurate practices, etc. Working with large data volumes during patient communication with clinicians, creating machine learning algorithms based on costs completely explain risk and changing complications [13].

Quality enhancement ascertained with an intense integration of machine practices created based on data and evidence generated. Changes from practices based on evidences extracted, like lack of proper usage of preventative models or interventions that reduce treatment value, are effectively recognized using continuous reviews that are recorded back into modeling [14]. Organizations are provided support for optimal outcomes and decreased patient reviews or readmission into the hospital while offering an optimized disease management service [15].

Empirical variables provide proof for firms on creating and deploying AI-driven episode analytics to determine an insightful view into financial opportunities and gains for clinical models [16]. Deceased need for admission into hospitals, enhanced care movement, logging every status

during entire care, enhancing service for acute cases post treatment provide direct solutions with lower spend claims.

Patient examination be concurrently enhanced with cost reduction and value-based care solutions.

4.3. Decision Support System for Clinician Service Performance

Table 3: Technology Supporting Different

Program or Entity	AI Application	Impact
Medicaid	Predictive analytics for high-utilizers	Early detection of patients likely to overuse services, enabling proactive care management.
Medicare	Claims-based risk stratification	Identifies chronic disease patients for targeted interventions, reducing hospital readmissions.
Children's Health Insurance Program (CHIP)	AI-driven episode grouping	Tracks pediatric utilization patterns, improving preventive care delivery.
Veterans Health Administration (VA)	Machine learning for claims and EHR data	Enhances mental health and chronic care management for veterans.
Community Health Centers	AI and CHWs for care coordination	Combines predictive models with community health worker outreach to reduce avoidable utilization and improve equity.

Episode analytics be an effective model for performance of each hospital or clinical staff through optimized decision support systems [17]. Conventional dashboards or performance measurement practices are critically dependent on measures that lapse in accounting for patient complications for each chronic episode [18]. Symmetry-based analytics help to create every clinical service to delivery insights and facilities fair services with adequate analysis about service quality, highly quality outcome.

Machine learning models are effective to provide standard episodes for risk adjustment and classify patients based on certain specific elements [19]. This will be an effective to easily provide services with streamlined value from healthcare services to payers while identifying high-performing clinicians. AI-driven models decrease values with dependency on benchmarks for cost to make them simpler, avoiding any additional fees [20]. This will be accomplished through pattern measurement, resources used for treatment, level of complication during treatment, and outcomes.

Decision support optimized using AI help to provide value with several payment models, like pooling payments with responsible care. Incentives for each episode management be effective with quality maintenance and predictive analytics [21]. This help and determine strategies to attain objectives. Reviews are dependent on episode-based continuous learning practices with service improvement models. Customized care plans created based on risk predictions that are inserted into workflows of clinical staff. Decision support tools effective for judgment augmentation and offers data-driven solutions with effective decisions [22]. Data-driven approaches foster accountable practices with a culture of delivering transparency solutions with quality through entire healthcare system.

5. Challenges and Limitations

5.1. Technical Challenges

Even though there is a potential to integrate AI measures to symmetry episode analytics. It leads to significant challenges within technical criteria. The primary and major issue is to scale computational capacity while processing larger datasets that mandate complicated processing power [23]. Training and implementing machine learning measures need to be precise for accurate outcome. Working in healthcare firms with expanded analytics through several population collected through various time zones mandate intensive performance of the model.

Heterogeneous data is complicated during implementation. Data that is extracted from numerous sources and databases (healthcare providers, bill payers, coding practices, etc.). This mandates stronger processing and preparation for accurate model valuation, avoiding any misleading details. Interpreting models during data analysis of technical issue [24]. Creating machine learning models with advanced tools, specifically functions also called black boxes or deep learning models help to generate predictions [25]. Precise predictions with balanced integration capacity help to avoid any technical issues.

5.2. Privacy and Ethics

Data privacy and sampling ethics is critical variables to implement analytics extracting AI-driven healthcare details. Data comprises of confidential patient data, and securing privacy of data mandates stronger adherence to governance policies [26]. Complying with GDPR, and HIPAA is essential for data sensitivity. AI systems are created with principles that are integrated with data privacy during design phases for accountable processing. Unfair or biased sampling leads to ethical risks. Data reflecting several departments through care access, social-economic solutions, or usability of healthcare [27]. IN case left unresolved, these biases lead to higher disproportion in marking high-risk cases.

Transparency and data ownership are essential factors, and stakeholders need to perceive the cruciality of data management of decisions based on AI analytics. Ethical ownership deliver benefits with AI-enhanced episode analysis [6].

5.3. Implementation Barriers and Adoption Resistance

Above technical issues and ethical concerns, cultural restrictions within healthcare establishments to work with new tools like AI-driven episode analytics create concerns

with disturbance in data flow [28]. Skepticism among hospitals, clinicians lead to challenging situation or complications.

6. Future Directions

6.1. AI advancements for Episode Analytics

AI-Symmetry Episode Analytics is dependent on adopting highly advanced machine learning measures. Creating reinforced learning tools provides several opportunities in continuously upgrading model for optimized outcomes, aligning to real-world situations and changing according to timely recommendations [29]. Collaborative training through entire organization supported through federated leading measures. Federated training models help to share unrefined data to respond to any privacy issues and optimize data applicability [30].

SHAP(Shapely additive explanations) plots could be utilized for assigning empirical aspects to depict contribution o features and distinctive predictions for modeling trends [7]. Developing patient-level visuals as such allows emphasizing the exclusive use of clinical concepts and depict risk forecasts, these support in enhanced interpretability and allows care providers to notice the impact of clinical plausibility and empowering exclusive intervention planning.

Using XAI or explainable AI measures help to improve performance and prominence for transparent insights explaining the behavior of each machine learning model and examine decision logic. Interpretability is optimized with XAI, with improved trust on clinicians and work within regulatory compliance models. Natural language processing or NLP be effective for expansion of analytics and work with unstructured data extracted from doctor summary, discharge details [31]. This data be loaded into models for each episode.

6.2. Predictive Modelling Scope Expansion

Predictive models created in forthcoming time are potentially extended above frequency usability and be utilized to resolve range events that are categorized as catastrophic. These include sudden changes in clinical condition, or complications that are likely to increase expenditure [32]. Longitudinal models to estimate and track health conditions and solutions offer intensive purview about deteriorating conditions of an ailment and timings for intervention to restore health. Using health determinants based on social values, like unstable housing, income that decides access to costly care, or geographics that makes it critical to access critical care services [33]. Creating a comprehensive risk analysis help design targeted programs.

6.3. Striving Towards Customized Healthcare with Proactive Services

Final target of AI-enhanced episode analytics is to help clinical services to change with changing Ailment while offering customized services. Customized profiles for health risks are created to analyze and deliver personal intervention programs that resolve clinical and other requirements of

society [34]. Continuous monitoring tools with real-time data feed from IoT devices help to adjust care and treatment.

7. Conclusion

Symmetry episode-based healthcare analytics processes are effective in addressing various tasks associated with claim processing and therapeutic decisions. The approach is suitable for developing projection forecasts compared with conventional processes for developing effective pricing models. They are highly effective for commercial medicine dispensing and reducing losses due to pricing. The model integrated with AI and ML for effective claim assessment and risk profiling. Such processes support in defining network entities as well as providing suitable inputs to generate value. The healthcare insurance industries, state and national level claim processing, as well as hospitals, are benefited with agreement developed according to these insights. The actuaries belonging to healthcare under government administration involve various plans, like public exchange and MEDICAID are effectively benefited with symmetry episode modeling empowered with automation tools and data learning. The model empower risk evaluation and developing strategic plans for delivering perceptions into various factors.

References

[1] R&I Editorial Team, "Global Medical Costs to Rise 9.8% in 2026, Returning to Single-Digit Growth," R&I, 13 October 2025. [Online]. Available: http://riskandinsurance.com/global-medical-costs-to-rise-9-8-in-2026-returning-to-single-digit-growth/. [Accessed 19 December 2025].

[2] R. Abeysinghe, A. Black, D. Kaduk, Y. Li, C. Reich, A. Davydov, L. Yao and L. Cui, "Towards quality improvement of vaccine concept mappings in the OMOP vocabulary with a semi-automated method," Journal of Biomedical Informatics, vol. 134, no. 1, pp. 1-8, 2022.

[3] Al-Nafjan, A. Aljuhani, A. Alshebel, A. Alharbi and A. Alshehri, "Artificial Intelligence in Predictive Healthcare: A Systematic Review," J. Clin. Med, vol. 14, no. 19, pp. 1-17, 2025.

[4] L. Beam and I. S. Kohane, "Big Data and Machine Learning in Health Care," JAMA, vol. 319, no. 13, pp. 1317-1318, 2018.

[5] M. N. A. Bhuiyan and R. S. Mondal, "AI-Driven Predictive Analytics in Healthcare: Evaluating Impact on Cost and Efficiency," Journal of Computational Analysis and Applications (JoCAAA), vol. 31, no. 4, p. 1355–1371, 2023.

[6] J. K. Tan, L. Quan, N. N. M. Salim, T. J. H, G. S. Y, T. J and B. Y. M, "Machine-learning based prediction for high health care utilizers using a multi-institution registry," European Journal of Public Health, vol. 34, no. 3, pp. 1-22, 2024.

[7] N. Nghiem, J. Atkinson, B. P. Nguyen, A. Tran-Duy and N. Wilson, "Predicting high health-cost users among people with cardiovascular disease using machine learning and nationwide linked social administrative

datasets," Health Economics Review, vol. 13, no. 9, pp. 1-13, 2023.

[8] G. Barenboim, J. Hirn and V. Sanz, "Symmetry meets AI," SciPost Physics, vol. 11, no. 014, pp. 1-10, 2021.

[9] D. Ravì, C. Wong, F. Deligianni, M. Berthelot, J. Andreu-Perez and B. Lo, "Deep Learning for Health Informatics," IEEE Journal of Biomedical and Health Informatics, vol. 21, no. 1, pp. 4-21, 2017.

[10] X. Zhang, H. Wu, T. Chen and G. Wang, "Automatic diagnosis of arrhythmia with electrocardiogram using multiple instance learning: From rhythm annotation to heartbeat prediction," Artificial Intelligence in Medicine, vol. 132, no. 1, pp. 1-12, 2022.

[11] M. L. Burns, S.-Y. Chen, C.-A. Tsai, J. Vandervest, B. Pandian, P. Nong, D. A. Hanauer, A. Rosenberg and J. Platt, "Generative AI costs in large healthcare systems, an example in revenue cycle," npj Digital Medicine, vol. 8, no. 579, pp. 1-5, 2025.

[12] H. Javed, S. El-Sappagh and T. Abuhmed, "Robustness in deep learning models for medical diagnostics: security and adversarial challenges towards robust AI applications," 2025, vol. 58, no. 12, pp. 1-107, 2025.

[13] J. Keck, C. Barry, C. Doeller and J. Jost, "Impact of symmetry in local learning rules on predictive neural representations and generalization in spatial navigation," PLOS Computational Biology, vol. 2025, no. 1, pp. 1-10, 2025.

[14] Holzinger, G. Langs, H. Denk, K. Zatloukal and H. Müller, "Causability and explainability of artificial intelligence in medicine," WIREs Data Mining and Knowledge Discovery, vol. 9, no. 4, pp. 1-20, 2019.

[15] Optum, "Symmetry Episode Risk Groups (ERG)," Optum, Inc, USA, 2022.

[16] S. Guleria, J. Guptill, I. Kumar, M. McClintic and J. C. Rojas, "Artificial intelligence integration in healthcare: perspectives and trends in a survey of U.S. health system leaders," BMC Digital Health, vol. 2, no. 80, pp. 1-8, 2024.

[17] L. I. Weil, L. R. Zwerwer, H. Chu, M. Verhoeff, P. P. Jeurissen and B. C. v. Munster, "Identifying future high healthcare utilization in patients with multimorbidity – development and internal validation of machine learning prediction models using electronic health record data," Health and Technology, vol. 14, no. 1, p. 433–449, 2024.

[18] A. Kunle and K. A. Taiwo, "Predictive Modeling for Healthcare Cost Analysis in the United States: A Comprehensive Review and Future Directions," International Journal of Scientific Research and Modern Technology, vol. 4, no. 1, p. 170–181, 2025.

[19] K. Lynch, B. Viernes, E. Gatsby, S. Knight, S. DuVall and J. Blosnich, "All-Cause and Suicide Mortality Among Lesbian, Gay, and Bisexual Veterans Who Utilize Care through the Veterans Health Administration," Health Services Research, vol. 55, no. S1, pp. 53-54, 2020.

[20] Y. Ma, X. Tu, X. Luo, L. Hu and C. Wang, "Machine-learning-based cost prediction models for inpatients with

mental disorders in China," BMC Psychiatry, vol. 25, no. 33, pp. 1-16, 2025.

[21] D. S. Mack, J. Baek, J. Tjia and K. L. Lapane, "Geographic Variation of Statin Use Among US Nursing Home Residents With Life-limiting Illness," Medical Care, vol. 59, no. 5, pp. 425-436, 2021..

[22] A. Mateen, J. Liley, A. K. Denniston, C. C. Holmes and S. J. Vollmer, "Improving the quality of machine learning in health applications and clinical research," Nature Machine Intelligence, vol. 2, no. 1, p. 554–556, 2020.

[23] Z. Obermeyer, B. Powers, C. Vogeli and S. Mullainathan, "Dissecting racial bias in an algorithm used to manage the health of populations," Science, vol. 366, no. 6464, pp. 447-453, 2019.

[24] Higgins, S. Racaniere and D. Rezende, "Symmetry-Based Representations for Artificial and Biological General Intelligence," Frontiers of Computing Neurosciences, vol. 16, no. 1, pp. 1-10, 2022.

[25] E. J. Topol, "High-performance medicine: the convergence of human and artificial intelligence," Nature Medicine, vol. 25, no. 1, p. 44–56, 2019.

[26] E. A. Seyam, "Predicting High-Cost Healthcare Utilization Using Machine Learning: A Multi-Service Risk Stratification Analysis in EU-Based Private Group Health Insurance," Risks, vol. 13, no. 7, pp. 1-19, 2025.

[27] R. Shalinirajan, S. S, V. Prithivirajan, S. D, P. Kurada and R. P, "Transforming Healthcare: AI Models for Predictive Analysis in Medical Applications," 4th Asian Conference on Innovation in Technology (ASIANCON), vol. 1, no. 1, pp. 1-6, 2024.

[28] E. H. Shortliffe and M. J. Sepúlveda, "Clinical Decision Support in the Era of Artificial Intelligence," JAMA, vol. 320, no. 21, pp. 2199-2200, 2018.

[29] Tae, H. Kong, J. Lee and Y. Lee, "Machine learning for disease-specific prediction of high-cost patients," Engineering Applications of Artificial Intelligence, vol. 161 C, no. 1, pp. 1-29, 2025.

[30] W. N. Price and I. G. Cohen, "Privacy in the age of medical big data," Nature Medicine, vol. 25, no. 1, p. 37–43, 2019.

[31] Y. Rahman and P. Dua, "A machine learning framework for predicting healthcare utilization and risk factors," Healthcare Analytics, vol. 8, no. 1, pp. 1-20, 2025.

[32] Rajkomar, J. Dean and I. Kohane, "Machine Learning in Medicine," N Engl J Med, vol. 380, no. 14, pp. 1347-1358, 2019.

[33] S. Ramesh, L. Shanmugam and S. Ramalingam, "Predictive Analytics for Healthcare Cost Control: Using AI/ML to Forecast Expenses and Manage Financial Sustainability," Journal of Artificial Intelligence Research, vol. 2, no. 1, pp. 306-346, 2022.

[34] R. Rao, R. Jain, M. Singh and R. Garg, "Predictive interpretable analytics models for forecasting healthcare costs using open healthcare data," Healthcare Analytics, vol. 6, no. 1, pp. 1-20, 2024.