PRD: Modul AI – Triage & EMR (Sokongan Klinikal Pintar)

Kod PRD: KLINIK-AI-PR2026-01-triage-emr-sokongan-klinikal **Dicipta:** 14 Januari 2026 **Penulis:** AI Assistant **Dikemaskini:** 14 Januari 2026

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1. Ringkasan Eksekutif

1.1 Gambaran Keseluruhan

Modul AI – Triage & EMR adalah sistem sokongan keputusan klinikal pintar yang menggunakan pendekatan Rule-based + Machine Learning hybrid untuk membantu doktor dan jururawat dalam proses triage pesakit, menjana ringkasan EMR automatik, dan memberikan cadangan klinikal berasaskan bukti. Sistem ini mengutamakan Explainable AI (XAI) dan Human-in-the-Loop untuk memastikan keselamatan pesakit dan kepercayaan pengguna.

1.2 Metadata

- **Nama Feature**: Sistem Sokongan Keputusan Klinikal Pintar (AI-CDSS)
- **Modul**: AI – Triage & EMR
- **Submodule**: Sokongan Klinikal Pintar
- **Peranan Sasaran**: Doktor, Jururawat
- **Keutamaan**: Tinggi
- **Status**: Perancangan
- **Anggaran Usaha**: Besar (20 minggu)

1.3 Objektif

- Mempercepatkan proses triage dengan AI-assisted symptom analysis dan severity scoring
- Menyediakan ringkasan EMR yang komprehensif untuk memudahkan keputusan klinikal
- Memberikan cadangan differential diagnosis dan rawatan berasaskan clinical guidelines
- Mengesan red flags dan drug interactions secara real-time untuk keselamatan pesakit
- Melaksanakan Explainable AI supaya setiap cadangan boleh difahami dan diaudit
- Memastikan Human-in-the-Loop dengan mandatory review untuk semua cadangan AI
- Mematuhi PDPA dan prinsip etika AI dalam pemprosesan data kesihatan

1.4 Skop

Dalam Skop:

- AI Triage dengan 5-level severity scoring (Manchester Triage System)
- Symptom checker dengan red flag detection
- Ringkasan EMR automatik (problem list, medications, allergies, chronic conditions)
- Cadangan differential diagnosis dengan confidence scores
- Drug interaction checking (drug-drug, drug-allergy, drug-disease)
- Explainable AI dengan reasoning chain dan clinical references
- Human-in-the-Loop mandatory review workflow
- Feedback loop untuk continuous improvement
- On-premise AI processing untuk PDPA compliance
- AI governance dan ethics monitoring

Luar Skop:

- Diagnosis definitif oleh AI (AI hanya memberi cadangan)
- Preskripsi automatik tanpa pengesahan doktor
- Imaging analysis (X-ray, CT, MRI AI interpretation)
- Predictive analytics untuk population health
- Natural Language Processing untuk voice input
- Telemedicine AI consultation
- Integration dengan external health information exchange

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2. Pernyataan Masalah

2.1 Masalah Semasa

Proses klinikal di klinik menghadapi beberapa cabaran:

- Triage manual memakan masa dan bergantung sepenuhnya kepada pengalaman individu
- Tiada sistem untuk mengesan red flags secara konsisten
- Doktor perlu scroll melalui rekod panjang EMR untuk mendapatkan gambaran keseluruhan
- Drug interactions kadang-kadang terlepas pandang terutama untuk pesakit dengan polypharmacy
- Tiada akses cepat kepada clinical guidelines semasa consultation
- Risiko salah tafsir simptom terutama untuk kes yang jarang ditemui
- Kepercayaan pengguna terhadap sistem AI masih rendah kerana kurang transparency

2.2 Impak Kepada Perniagaan

- **Keselamatan Pesakit**: Risiko missed diagnosis atau delayed treatment untuk kes kritikal
- **Kecekapan**: Masa consultation yang panjang kerana perlu review rekod secara manual
- **Kualiti**: Variasi dalam kualiti triage bergantung kepada siapa yang bertugas
- **Compliance**: Risiko drug interactions yang tidak dikesan
- **Kepuasan**: Pesakit menunggu lama kerana proses triage yang lambat

2.3 Hasil Yang Diingini

- Triage yang konsisten dan cepat dengan AI-assisted severity scoring
- Red flags dikesan secara real-time dengan alert yang jelas
- Ringkasan EMR tersedia dalam satu pandangan untuk setiap pesakit
- Drug interactions dikesan sebelum preskripsi ditulis
- Cadangan AI yang boleh dijelaskan dan diaudit
- Doktor dan jururawat mempercayai sistem kerana transparency dan control
- Zero critical missed diagnoses dengan AI backup

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3. User Stories

3.1 User Stories Utama

- **Sebagai** Jururawat triage, **saya mahu** memasukkan simptom pesakit dan mendapat skor severity automatik **supaya** saya boleh prioritize pesakit dengan cepat dan konsisten

- **Sebagai** Doktor, **saya mahu** melihat ringkasan EMR pesakit dalam satu pandangan **supaya** saya tidak perlu scroll melalui rekod panjang dan boleh fokus kepada konsultasi

- **Sebagai** Doktor, **saya mahu** mendapat cadangan differential diagnosis berdasarkan simptom **supaya** saya tidak terlepas pandang kemungkinan diagnosis yang jarang

- **Sebagai** Doktor, **saya mahu** melihat penjelasan mengapa AI mencadangkan sesuatu diagnosis **supaya** saya boleh menilai kesesuaian cadangan tersebut

- **Sebagai** Doktor, **saya mahu** sistem alert saya tentang drug interactions sebelum saya tulis preskripsi **supaya** keselamatan pesakit terjamin

- **Sebagai** Jururawat, **saya mahu** sistem alert saya apabila pesakit mempunyai red flags **supaya** saya boleh escalate kepada doktor dengan segera

- **Sebagai** Doktor, **saya mahu** mengesahkan atau menolak cadangan AI dengan satu klik **supaya** workflow saya tidak terganggu

- **Sebagai** Doktor, **saya mahu** memberi feedback kepada sistem apabila cadangan AI tidak tepat **supaya** sistem boleh improve dari masa ke masa

- **Sebagai** Pengurus Klinik, **saya mahu** melihat laporan prestasi AI **supaya** saya boleh memastikan sistem berfungsi dengan baik dan selamat
- **Sebagai** Doktor, **saya mahu** akses kepada clinical guidelines yang relevan untuk kes semasa **supaya** keputusan saya berasaskan bukti terkini

3.2 Edge Cases & User Stories Sekunder

- **Sebagai** Doktor, **bila** AI mempunyai confidence rendah (<70%), **saya sepatutnya** melihat warning yang jelas dan cadangan untuk refer kepada pakar
- **Sebagai** Jururawat, **bila** sistem mengesan simptom life-threatening, **saya sepatutnya** melihat alert merah yang tidak boleh diabaikan dan langkah tindakan segera
- **Sebagai** Doktor, **bila** AI tidak dapat memberikan cadangan kerana data tidak mencukupi, **saya sepatutnya** melihat senarai maklumat tambahan yang diperlukan
- **Sebagai** Doktor, **bila** terdapat contraindication antara ubat dengan penyakit kronik pesakit, **saya sepatutnya** melihat alert dengan penjelasan dan alternatif
- **Sebagai** Jururawat, **bila** pesakit mempunyai allergy yang direkodkan, **saya sepatutnya** melihat alert jika ubat yang dicadangkan berkaitan dengan allergen tersebut
- **Sebagai** Pengurus, **bila** berlaku insiden berkaitan cadangan AI, **saya sepatutnya** dapat menjejaki audit trail lengkap untuk siasatan
- **Sebagai** Doktor, **bila** saya tidak bersetuju dengan cadangan AI, **saya sepatutnya** dapat override dengan justifikasi dan sistem merekodkan keputusan saya
- **Sebagai** Admin, **bila** model AI dikemaskini, **saya sepatutnya** melihat versioning dan changelog untuk transparency

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4. Keperluan Fungsian

4.1 AI Triage System (FR-100 Series)

- ☑ **FR-101:** Sistem mesti menyediakan symptom checker dengan input berstruktur (body region, symptom type, duration, severity)
- ☑ **FR-102:** Sistem mesti mengira severity score menggunakan 5-level Manchester Triage System (Emergency, Urgent, Semi-urgent, Standard, Non-urgent)
- ☑ **FR-103:** Sistem mesti mengesan red flags (life-threatening symptoms) dan memaparkan alert merah yang prominent
- ☑ **FR-104:** Sistem mesti mencadangkan urgency classification dengan reasoning yang boleh dijelaskan
- ☑ **FR-105:** Sistem mesti memaparkan recommended actions berdasarkan triage level (contoh: "Lihat doktor segera", "Boleh tunggu 30 minit")
- ☑ **FR-106:** Sistem mesti auto-populate triage form berdasarkan chief complaint yang dimasukkan
- ☑ **FR-107:** Sistem mesti merekodkan semua input triage dan keputusan untuk audit
- ☑ **FR-108:** Sistem mesti membenarkan override triage level dengan justifikasi

4.2 EMR Summary Generation (FR-200 Series)

- ☑ **FR-201:** Sistem mesti generate ringkasan EMR automatik apabila pesakit dipanggil untuk consultation
- ☑ **FR-202:** Ringkasan mesti mengandungi: Active Problem List, Current Medications, Allergies, Chronic Conditions, Recent Visits (6 bulan)
- ☑ **FR-203:** Sistem mesti highlight critical information (allergies, contraindications, abnormal lab values)
- ☑ **FR-204:** Sistem mesti memaparkan medication adherence trends jika data available
- ☑ **FR-205:** Sistem mesti memaparkan vital signs trends dalam bentuk mini-chart
- ☑ **FR-206:** Sistem mesti memaparkan lab results trends untuk chronic disease monitoring (HbA1c, cholesterol, BP)

- **FR-207:** Ringkasan mesti boleh di-expand untuk detail penuh atau di-collapse untuk quick view
- **FR-208:** Sistem mesti highlight bila last visit lebih dari 6 bulan (potential lost to follow-up)

4.3 Clinical Decision Support (FR-300 Series)

- **FR-301:** Sistem mesti mencadangkan differential diagnosis berdasarkan symptoms dan patient history
- **FR-302:** Setiap cadangan diagnosis mesti mempunyai confidence score (0-100%)
- **FR-303:** Sistem mesti memaparkan reasoning chain yang menjelaskan kenapa diagnosis dicadangkan
- **FR-304:** Sistem mesti menyenaraikan supporting evidence dari EMR yang menyokong setiap cadangan
- **FR-305:** Sistem mesti mencadangkan investigations yang relevan untuk confirm/exclude diagnosis
- **FR-306:** Sistem mesti mencadangkan treatment options berdasarkan clinical guidelines
- **FR-307:** Sistem mesti link ke clinical guidelines (MOH, WHO) yang berkaitan
- **FR-308:** Cadangan mesti dikategorikan mengikut confidence level: High (>85%), Medium (70-85%), Low (<70%)

4.4 Drug Interaction & Safety Alerts (FR-400 Series)

- **FR-401:** Sistem mesti check drug-drug interactions untuk semua medications (current + new)
- **FR-402:** Sistem mesti check drug-allergy interactions berdasarkan recorded allergies
- **FR-403:** Sistem mesti check drug-disease contraindications berdasarkan problem list
- **FR-404:** Sistem mesti check drug-food interactions untuk critical medications
- **FR-405:** Sistem mesti validate dosage berdasarkan patient weight, age, dan renal function
- **FR-406:** Interactions mesti dikategorikan: Severe (block prescription), Moderate (warning), Mild (info)
- **FR-407:** Sistem mesti memaparkan alternative medications jika ada contraindication
- **FR-408:** Sistem mesti require override justification untuk severe interactions

4.5 Explainable AI (FR-500 Series)

- **FR-501:** Setiap cadangan AI mesti mempunyai confidence score yang visible
- **FR-502:** Sistem mesti memaparkan reasoning chain dalam bahasa yang mudah difahami
- **FR-503:** Sistem mesti highlight risk factors yang menyumbang kepada cadangan
- **FR-504:** Sistem mesti link ke clinical references (guidelines, studies) yang menyokong cadangan
- **FR-505:** Sistem mesti memaparkan similar past cases (anonymized) jika relevan
- **FR-506:** Sistem mesti explain limitations dan uncertainties dalam cadangan
- **FR-507:** Sistem mesti memaparkan "What-if" analysis (contoh: "Jika umur >60, risk score akan meningkat")

4.6 Human-in-the-Loop (FR-600 Series)

- **FR-601:** Semua cadangan AI mesti disemak dan disahkan oleh doktor/jururawat sebelum tindakan
- **FR-602:** Sistem mesti menyediakan button "Accept", "Reject", "Modify" untuk setiap cadangan
- **FR-603:** Bila reject/modify, sistem mesti require justification dari clinician
- **FR-604:** Low confidence predictions (<70%) mesti auto-flag untuk senior doctor review
- **FR-605:** Critical alerts mesti require explicit acknowledgement sebelum proceed
- **FR-606:** Sistem mesti merekodkan semua decisions (accept/reject/modify) untuk audit
- **FR-607:** Sistem mesti escalate unacknowledged critical alerts selepas timeout (5 minit)

4.7 Feedback & Learning Loop (FR-700 Series)

- **FR-701:** Sistem mesti membenarkan clinicians rate cadangan AI (helpful/not helpful/incorrect)
- **FR-702:** Sistem mesti collect actual diagnosis outcome untuk comparison dengan AI prediction
- **FR-703:** Sistem mesti learn dari corrections dan improve model secara berkala
- **FR-704:** Sistem mesti track accuracy metrics per category (diagnosis type, symptom type)
- **FR-705:** Sistem mesti identify patterns where AI consistently underperforms
- **FR-706:** Feedback mesti de-identified sebelum digunakan untuk model training

4.8 Red Flag Detection (FR-800 Series)

- ☑ **FR-801:** Sistem mesti detect life-threatening symptoms (chest pain, difficulty breathing, stroke symptoms, etc.)
- ☑ **FR-802:** Sistem mesti detect critical lab values (severely abnormal results)
- ☑ **FR-803:** Sistem mesti detect deteriorating trends (worsening vitals, declining renal function)
- ☑ **FR-804:** Sistem mesti detect drug allergies dengan high severity
- ☑ **FR-805:** Sistem mesti detect contraindications untuk existing conditions
- ☑ **FR-806:** Red flags mesti trigger immediate visual + audio alert
- ☑ **FR-807:** Red flags mesti tidak boleh dismissed tanpa explicit acknowledgement
- ☑ **FR-808:** Sistem mesti log semua red flag alerts dan responses

4.9 Clinical Knowledge Base (FR-900 Series)

- ☑ **FR-901:** Sistem mesti integrate dengan MOH clinical guidelines
- ☑ **FR-902:** Sistem mesti integrate dengan WHO guidelines
- ☑ **FR-903:** Sistem mesti integrate dengan drug database (MIMS atau equivalent)
- ☑ **FR-904:** Sistem mesti support ICD-10/ICD-11 coding
- ☑ **FR-905:** Sistem mesti support local clinic protocols
- ☑ **FR-906:** Knowledge base mesti versioned dan updateable
- ☑ **FR-907:** Sistem mesti track bila guidelines dikemaskini dan notify admin
- ☑ **FR-908:** Sistem mesti allow clinic to add custom protocols

4.10 AI Governance & Ethics (FR-1000 Series)

- ☑ **FR-1001:** Sistem mesti maintain complete audit trail untuk semua AI decisions
- ☑ **FR-1002:** Sistem mesti track AI model versioning dengan changelog
- ☑ **FR-1003:** Sistem mesti monitor AI performance metrics (accuracy, precision, recall)
- ☑ **FR-1004:** Sistem mesti detect dan report potential bias dalam predictions
- ☑ **FR-1005:** Sistem mesti provide incident reporting mechanism untuk AI-related issues
- ☑ **FR-1006:** Sistem mesti allow rollback ke previous model version jika issues detected
- ☑ **FR-1007:** Sistem mesti generate monthly AI performance report
- ☑ **FR-1008:** Semua AI processing mesti on-premise untuk PDPA compliance

4.2 Kebenaran & Kawalan Akses

Peranan Diperlukan:

- Doktor: Full access ke semua AI features
- Jururawat: Triage, EMR summary, red flag alerts (tiada clinical decision support)
- Admin: AI governance, performance monitoring, knowledge base management

Kebenaran Diperlukan:

Permission	Doktor	Jururawat	Admin
`ai.triage.view`	✓	✓	✓
`ai.triage.execute`	✓	✓	✗
`ai.triage.override`	✓	✗	✗
`ai.emr_summary.view`	✓	✓	✗
`ai.diagnosis.view`	✓	✗	✗
`ai.diagnosis.accept_reject`	✓	✗	✗

`ai.drug_check.view`	✓	✓	✗
`ai.drug_check.override`	✓	✗	✗
`ai.feedback.submit`	✓	✓	✗
`ai.governance.view`	✓	✗	✓
`ai.governance.manage`	✗	✗	✓
`ai.knowledge_base.view`	✓	✓	✓
`ai.knowledge_base.manage`	✗	✗	✓

Authorization Logic:

- Doktor mesti MMC-registered untuk akses clinical decision support
- Senior doctor review required untuk low-confidence cases
- Admin tidak boleh akses patient data, hanya aggregated AI metrics
- All AI interactions logged dengan user identity

4.3 Validasi Data

Field Wajib - Triage Input:

- `chief_complaint` : Required, string, max 500
- `symptoms` : Required, array of symptom objects
- `onset` : Required, enum (minutes, hours, days, weeks, months)
- `severity_patient` : Required, 1-10 scale
- `vital_signs` : Required for full triage (BP, HR, RR, Temp, SpO2)

Field Wajib - Feedback:

- `prediction_id` : Required, exists in predictions table
- `rating` : Required, enum (helpful, not_helpful, incorrect)
- `actual_diagnosis` : Optional, ICD-10 code (for outcome tracking)
- `comments` : Optional, string, max 1000

Peraturan Validasi:

- Symptoms mesti valid dari symptom ontology
- Vital signs mesti dalam physiologically possible range
- ICD-10 codes mesti valid format
- Drug codes mesti valid MIMS codes

Peraturan Perniagaan:

- AI cadangan tidak boleh disimpan tanpa human review
- Critical alerts mesti acknowledged dalam 5 minit
- Override justification mesti minimum 10 characters
- Low confidence cases mesti escalate ke senior

4.4 Audit Trail & PDPA Compliance

- ☑ **Adakah feature ini perlu audit trail?** Ya - Kritikal
- **Field Audit**: created_by, updated_by, timestamp untuk semua AI interactions
- **Data Consent**: Pesakit mesti consent untuk AI-assisted care (dalam general consent)
- **Data Retention**: AI prediction logs disimpan 7 tahun, training data de-identified

Audit Events:

Event Category	Events
Triage	triage_initiated, triage_completed, triage_overridden
EMR Summary	summary_generated, summary_viewed
Clinical Decision	prediction_generated, prediction_accepted, prediction_rejected, prediction_modified
Drug Safety	interaction_detected, interaction_acknowledged, interaction_overridden
Red Flag	red_flag_triggered, red_flag_acknowledged, red_flag_escalated
Feedback	feedback_submitted, outcome_recorded
Governance	model_updated, knowledge_base_updated, incident_reported

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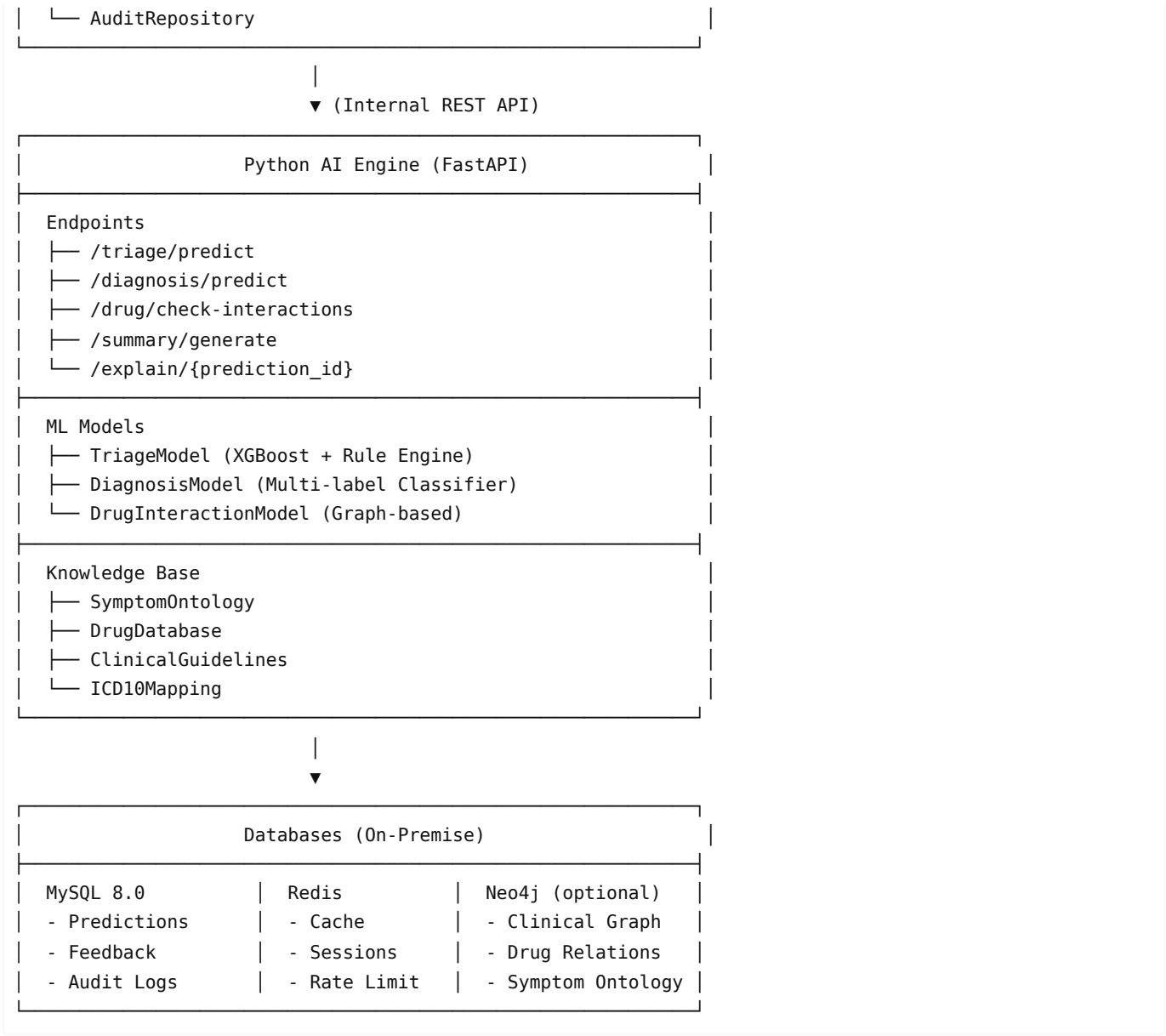
5. Keperluan Teknikal

5.1 Teknologi Stack

- **Framework**: Laravel 12
- **Frontend**: Blade Templates + Bootstrap 5 + CoreUI + Alpine.js (for reactivity)
- **Database**: MySQL 8.0
- **AI/ML Framework**: Python (FastAPI) with scikit-learn, XGBoost untuk ML models
- **AI Communication**: Laravel ↔ FastAPI via internal REST API
- **Knowledge Graph**: Neo4j atau equivalent untuk clinical ontology
- **Cache**: Redis untuk caching predictions dan knowledge base
- **Queue**: Laravel Queue (Redis driver) untuk async AI processing
- **File Storage**: Local storage untuk model artifacts
- **Logging**: ELK Stack atau equivalent untuk AI audit logs

5.2 Arsitektur Aplikasi

```
┌─────────────────────────────────────────────────────────┐
│                   Laravel Application                   │
├─────────────────────────────────────────────────────────┤
│  Controller Layer                                       │
│  ├── AiTriageController                                 │
│  ├── AiSummaryController                                │
│  ├── AiDiagnosisController                              │
│  ├── AiDrugCheckController                              │
│  └── AiGovernanceController                             │
├─────────────────────────────────────────────────────────┤
│  Service Layer                                          │
│  ├── TriageService                                      │
│  ├── EmrSummaryService                                  │
│  ├── ClinicalDecisionService                            │
│  ├── DrugInteractionService                             │
│  ├── ExplainabilityService                              │
│  └── AiGovernanceService                                │
├─────────────────────────────────────────────────────────┤
│  AI Gateway (Internal API Client)                       │
│  └── AiEngineClient (communicates with Python AI Engine)│
├─────────────────────────────────────────────────────────┤
│  Repository Layer                                       │
│  ├── PredictionRepository                               │
│  ├── FeedbackRepository                                 │
```



5.3 Struktur Modul

```
app/
├── Http/
│   ├── Controllers/
│   │   └── Admin/
│   │       └── AI/
│   │           ├── TriageController.php
│   │           ├── SummaryController.php
│   │           ├── DiagnosisController.php
│   │           ├── DrugCheckController.php
│   │           ├── FeedbackController.php
│   │           └── GovernanceController.php
│   ├── Requests/
│   │   ├── TriageRequest.php
│   │   ├── DiagnosisFeedbackRequest.php
│   │   └── OverrideRequest.php
│   └── Middleware/
│       ├── EnsureAiConsent.php
│       └── LogAiInteraction.php
```

```
├── Services/
│   └── AI/
│       ├── TriageService.php
│       ├── EmrSummaryService.php
│       ├── ClinicalDecisionService.php
│       ├── DrugInteractionService.php
│       ├── ExplainabilityService.php
│       ├── FeedbackService.php
│       ├── AiGovernanceService.php
│       └── AiEngineClient.php
├── Repositories/
│   └── AI/
│       ├── PredictionRepository.php
│       ├── FeedbackRepository.php
│       ├── KnowledgeBaseRepository.php
│       └── AiAuditRepository.php
├── Models/
│   ├── AiPrediction.php
│   ├── AiTriageResult.php
│   ├── AiDiagnosisSuggestion.php
│   ├── AiDrugAlert.php
│   ├── AiFeedback.php
│   ├── AiRedFlagAlert.php
│   ├── AiModelVersion.php
│   ├── AiAuditLog.php
│   ├── ClinicalGuideline.php
│   └── DrugInteraction.php
├── Events/
│   ├── RedFlagDetected.php
│   ├── CriticalAlertTriggered.php
│   └── PredictionGenerated.php
├── Listeners/
│   ├── NotifyRedFlagAlert.php
│   ├── EscalateCriticalAlert.php
│   └── LogPrediction.php
├── Jobs/
│   ├── GenerateEmrSummary.php
│   ├── CheckDrugInteractions.php
│   └── ProcessFeedback.php
└── Notifications/
    ├── RedFlagAlertNotification.php
    ├── CriticalEscalationNotification.php
    └── LowConfidenceWarningNotification.php

ai-engine/ (Python FastAPI - separate service)
├── app/
│   ├── main.py
│   ├── api/
│   │   ├── triage.py
│   │   ├── diagnosis.py
│   │   ├── drug_check.py
│   │   ├── summary.py
│   │   └── explain.py
│   ├── models/
│   │   ├── triage_model.py
│   │   ├── diagnosis_model.py
```

```
│   │   └── interaction_model.py
│   ├── knowledge/
│   │   ├── symptom_ontology.py
│   │   ├── drug_database.py
│   │   ├── guidelines.py
│   │   └── icd_mapping.py
│   ├── explainability/
│   │   ├── shap_explainer.py
│   │   └── reasoning_chain.py
│   └── config/
│       └── settings.py
├── models/  (trained model files)
│   ├── triage_v1.0.pkl
│   ├── diagnosis_v1.0.pkl
│   └── interaction_v1.0.pkl
├── data/  (knowledge base data)
│   ├── symptoms.json
│   ├── drugs.json
│   ├── guidelines.json
│   └── icd10.json
└── requirements.txt

config/
├── ai.php
└── ai_governance.php

resources/
└── views/
    └── admin/
        └── ai/
            ├── triage/
            │   ├── form.blade.php
            │   └── result.blade.php
            ├── summary/
            │   └── panel.blade.php
            ├── diagnosis/
            │   └── suggestions.blade.php
            ├── drug-check/
            │   └── alerts.blade.php
            └── governance/
                ├── dashboard.blade.php
                ├── performance.blade.php
                └── incidents.blade.php
```

5.4 Database Schema

Jadual: `ai_predictions`

Column	Type	Description
`id`	bigint UNSIGNED PK	Primary key
`uuid`	uuid UNIQUE NOT NULL	Unique identifier for tracking
`pesakit_id`	bigint UNSIGNED NOT NULL	FK → pesakit.id
`encounter_id`	bigint UNSIGNED NULL	FK → encounters.id

`prediction_type`	enum NOT NULL	triage/diagnosis/drug_check/summary
`model_version`	varchar(20) NOT NULL	AI model version used
`input_data`	json NOT NULL	Input data (encrypted)
`output_data`	json NOT NULL	Prediction output (encrypted)
`confidence_score`	decimal(5,2) NULL	Overall confidence (0-100)
`confidence_level`	enum NULL	high/medium/low
`explanation`	json NULL	XAI reasoning chain
`status`	enum NOT NULL	pending/reviewed/accepted/rejected/modified
`reviewed_by`	bigint UNSIGNED NULL	FK → users.id
`reviewed_at`	datetime NULL	Review timestamp
`review_action`	enum NULL	accept/reject/modify
`review_justification`	text NULL	Justification for reject/modify
`processing_time_ms`	int NULL	Processing time in milliseconds
`created_by`	bigint UNSIGNED NULL	FK → users.id
`created_at`	timestamp	Created timestamp
`updated_at`	timestamp	Updated timestamp

Indexes:

- `idx_prediction_pesakit` on `pesakit_id`
- `idx_prediction_type` on `prediction_type`
- `idx_prediction_status` on `status`
- `idx_prediction_created` on `created_at`

Jadual: `ai_triage_results`

Column	Type	Description
`id`	bigint UNSIGNED PK	Primary key
`prediction_id`	bigint UNSIGNED NOT NULL	FK → ai_predictions.id
`chief_complaint`	text NOT NULL	Chief complaint text
`symptoms`	json NOT NULL	Array of symptoms
`vital_signs`	json NULL	Vital signs data
`severity_score`	int NOT NULL	1-5 (Manchester)
`severity_label`	enum NOT NULL	emergency/urgent/semi_urgent/standard/non_urgent
`urgency_minutes`	int NULL	Recommended wait time
`red_flags`	json NULL	Detected red flags
`recommended_actions`	json NULL	Recommended next steps
`overridden`	boolean DEFAULT false	Was overridden by clinician

`override_severity`	enum NULL	Overridden severity level
`override_reason`	text NULL	Override justification
`created_at`	timestamp	Created timestamp

Indexes:

- `idx_triage_prediction` on `prediction_id`
- `idx_triage_severity` on `severity_label`

Jadual: `ai_diagnosis_suggestions`

Column	Type	Description
`id`	bigint UNSIGNED PK	Primary key
`prediction_id`	bigint UNSIGNED NOT NULL	FK → ai_predictions.id
`rank`	int NOT NULL	Rank order (1 = most likely)
`icd_code`	varchar(10) NOT NULL	ICD-10 code
`diagnosis_name`	varchar(255) NOT NULL	Diagnosis name (BM/EN)
`confidence_score`	decimal(5,2) NOT NULL	Confidence (0-100)
`supporting_evidence`	json NOT NULL	Evidence from EMR
`reasoning_chain`	json NOT NULL	Step-by-step reasoning
`risk_factors`	json NULL	Contributing risk factors
`recommended_investigations`	json NULL	Suggested tests
`recommended_treatments`	json NULL	Treatment guidelines
`clinical_references`	json NULL	Links to guidelines
`is_accepted`	boolean NULL	Clinician decision
`created_at`	timestamp	Created timestamp

Indexes:

- `idx_diagnosis_prediction` on `prediction_id`
- `idx_diagnosis_icd` on `icd_code`

Jadual: `ai_drug_alerts`

Column	Type	Description
`id`	bigint UNSIGNED PK	Primary key
`prediction_id`	bigint UNSIGNED NOT NULL	FK → ai_predictions.id
`alert_type`	enum NOT NULL	drug_drug/drug_allergy/drug_disease/drug_food/dosage
`severity`	enum NOT NULL	severe/moderate/mild
`drug_1_code`	varchar(20) NOT NULL	First drug code
`drug_1_name`	varchar(255) NOT NULL	First drug name

drug_2_code	varchar(20) NULL	Second drug/allergen/disease code
drug_2_name	varchar(255) NULL	Second drug/allergen/disease name
interaction_description	text NOT NULL	Description of interaction
clinical_significance	text NOT NULL	Clinical impact
recommendation	text NOT NULL	Recommended action
alternatives	json NULL	Alternative medications
references	json NULL	Clinical references
acknowledged	boolean DEFAULT false	Clinician acknowledged
acknowledged_by	bigint UNSIGNED NULL	FK → users.id
acknowledged_at	datetime NULL	Acknowledgement time
overridden	boolean DEFAULT false	Alert overridden
override_reason	text NULL	Override justification
created_at	timestamp	Created timestamp

Indexes:

- `idx_drug_alert_prediction` on `prediction_id`
- `idx_drug_alert_severity` on `severity`
- `idx_drug_alert_type` on `alert_type`

Jadual: `ai_red_flag_alerts`

Column	Type	Description
id	bigint UNSIGNED PK	Primary key
prediction_id	bigint UNSIGNED NOT NULL	FK → ai_predictions.id
pesakit_id	bigint UNSIGNED NOT NULL	FK → pesakit.id
flag_type	enum NOT NULL	life_threatening/critical_lab/deteriorating/allergy/contraindication
flag_code	varchar(50) NOT NULL	Internal flag code
flag_description	text NOT NULL	Description
urgency_level	enum NOT NULL	immediate/urgent/soon
recommended_action	text NOT NULL	What to do
triggered_at	datetime NOT NULL	When triggered
acknowledged	boolean DEFAULT false	Acknowledged
acknowledged_by	bigint UNSIGNED NULL	FK → users.id
acknowledged_at	datetime NULL	Acknowledgement time
escalated	boolean DEFAULT false	Was escalated
escalated_at	datetime NULL	Escalation time

`escalated_to`	bigint UNSIGNED NULL	FK → users.id
`resolution_status`	enum NULL	resolved/false_positive/referred
`resolution_notes`	text NULL	Resolution notes
`resolved_by`	bigint UNSIGNED NULL	FK → users.id
`resolved_at`	datetime NULL	Resolution time
`created_at`	timestamp	Created timestamp

Indexes:

- `idx_red_flag_pesakit` on `pesakit_id`
- `idx_red_flag_acknowledged` on `acknowledged`
- `idx_red_flag_triggered` on `triggered_at`

Jadual: `ai_feedback`

Column	Type	Description
`id`	bigint UNSIGNED PK	Primary key
`prediction_id`	bigint UNSIGNED NOT NULL	FK → ai_predictions.id
`feedback_type`	enum NOT NULL	rating/outcome/correction
`rating`	enum NULL	helpful/not_helpful/incorrect
`actual_diagnosis_icd`	varchar(10) NULL	Actual diagnosis (outcome)
`actual_diagnosis_name`	varchar(255) NULL	Actual diagnosis name
`correction_details`	json NULL	Correction information
`comments`	text NULL	Free text comments
`is_used_for_training`	boolean DEFAULT false	Used for model training
`de_identified_at`	datetime NULL	When de-identified
`submitted_by`	bigint UNSIGNED NOT NULL	FK → users.id
`created_at`	timestamp	Created timestamp

Indexes:

- `idx_feedback_prediction` on `prediction_id`
- `idx_feedback_rating` on `rating`

Jadual: `ai_model_versions`

Column	Type	Description
`id`	bigint UNSIGNED PK	Primary key
`model_type`	enum NOT NULL	triage/diagnosis/drug_check
`version`	varchar(20) NOT NULL	Version number (semver)
`description`	text NULL	Version description

`changelog`	json NULL	Changes in this version
`performance_metrics`	json NULL	Accuracy, precision, recall
`training_data_summary`	json NULL	Summary of training data
`is_active`	boolean DEFAULT false	Currently active version
`activated_at`	datetime NULL	Activation time
`deactivated_at`	datetime NULL	Deactivation time
`deployed_by`	bigint UNSIGNED NULL	FK → users.id
`created_at`	timestamp	Created timestamp
`updated_at`	timestamp	Updated timestamp

Indexes:

- `idx_model_version_type` on `model_type`
- `idx_model_version_active` on `is_active`

Jadual: `ai_audit_logs`

Column	Type	Description
`id`	bigint UNSIGNED PK	Primary key
`event_type`	varchar(50) NOT NULL	Event type
`event_category`	varchar(50) NOT NULL	Category
`prediction_id`	bigint UNSIGNED NULL	FK → ai_predictions.id
`pesakit_id`	bigint UNSIGNED NULL	FK → pesakit.id
`user_id`	bigint UNSIGNED NULL	FK → users.id
`model_version`	varchar(20) NULL	Model version
`action`	varchar(100) NOT NULL	Action performed
`details`	json NULL	Additional details
`ip_address`	varchar(45) NULL	IP address
`user_agent`	text NULL	User agent
`created_at`	timestamp NOT NULL	Event timestamp

Indexes:

- `idx_ai_audit_event` on `event_type`
- `idx_ai_audit_prediction` on `prediction_id`
- `idx_ai_audit_user` on `user_id`
- `idx_ai_audit_created` on `created_at`

Partitioning:

- Partition by RANGE on `created_at` (monthly partitions)

Jadual: `ai_incidents`

Column	Type	Description
id	bigint UNSIGNED PK	Primary key
incident_code	varchar(20) UNIQUE NOT NULL	INC-YYYYMMDD-XXXX
prediction_id	bigint UNSIGNED NULL	FK → ai_predictions.id
incident_type	enum NOT NULL	missed_diagnosis/false_positive/system_error/patient_harm
severity	enum NOT NULL	critical/high/medium/low
title	varchar(255) NOT NULL	Incident title
description	text NOT NULL	Detailed description
patient_impact	text NULL	Impact on patient
root_cause	text NULL	Root cause analysis
corrective_action	text NULL	Corrective action taken
status	enum NOT NULL	reported/investigating/resolved/closed
reported_by	bigint UNSIGNED NOT NULL	FK → users.id
assigned_to	bigint UNSIGNED NULL	FK → users.id
resolved_by	bigint UNSIGNED NULL	FK → users.id
resolved_at	datetime NULL	Resolution time
created_at	timestamp	Created timestamp
updated_at	timestamp	Updated timestamp

Indexes:

- `idx_incident_type` on `incident_type`
- `idx_incident_status` on `status`
- `idx_incident_severity` on `severity`

Jadual: `clinical_guidelines`

Column	Type	Description
id	bigint UNSIGNED PK	Primary key
source	enum NOT NULL	moh/who/nice/local
code	varchar(50) UNIQUE NOT NULL	Guideline code
title	varchar(255) NOT NULL	Title
category	varchar(100) NOT NULL	Clinical category
icd_codes	json NULL	Related ICD codes
content	longtext NOT NULL	Guideline content
version	varchar(20) NOT NULL	Guideline version
effective_date	date NOT NULL	Effective date

`expiry_date`	date NULL	Expiry date
`url`	varchar(500) NULL	Source URL
`is_active`	boolean DEFAULT true	Active status
`created_at`	timestamp	Created timestamp
`updated_at`	timestamp	Updated timestamp

Indexes:

- `idx_guideline_source` on `source`
- `idx_guideline_category` on `category`
- `idx_guideline_active` on `is_active`

Jadual: `drug_interactions`

Column	Type	Description
`id`	bigint UNSIGNED PK	Primary key
`interaction_type`	enum NOT NULL	drug_drug/drug_allergy/drug_disease/drug_food
`drug_1_code`	varchar(20) NOT NULL	First drug code
`drug_1_name`	varchar(255) NOT NULL	First drug name
`interactant_code`	varchar(50) NOT NULL	Interactant code
`interactant_name`	varchar(255) NOT NULL	Interactant name
`severity`	enum NOT NULL	severe/moderate/mild
`description`	text NOT NULL	Interaction description
`mechanism`	text NULL	Mechanism of interaction
`clinical_effect`	text NOT NULL	Clinical effect
`management`	text NOT NULL	Management recommendation
`evidence_level`	enum NULL	established/probable/suspected/possible
`references`	json NULL	Literature references
`source`	varchar(50) NOT NULL	Data source (MIMS, etc.)
`is_active`	boolean DEFAULT true	Active status
`created_at`	timestamp	Created timestamp
`updated_at`	timestamp	Updated timestamp

Indexes:

- `idx_interaction_drug1` on `drug_1_code`
- `idx_interaction_interactant on interactant_code`
- `idx_interaction_type` on `interaction_type`
- `idx_interaction_severity` on `severity`

5.5 Configuration Files

File: `config/ai.php`

```php
<?php

return [
    /*
    |--------------------------------------------------------------------------
    | AI Engine Configuration
    |--------------------------------------------------------------------------
    */
    'engine' => [
        'base_url' => env('AI_ENGINE_URL', 'http://localhost:8000'),
        'timeout' => env('AI_ENGINE_TIMEOUT', 30),
        'retry_attempts' => 3,
        'api_key' => env('AI_ENGINE_API_KEY'),
    ],

    /*
    |--------------------------------------------------------------------------
    | Triage Configuration
    |--------------------------------------------------------------------------
    */
    'triage' => [
        'enabled' => true,
        'model_version' => 'v1.0',

        'severity_levels' => [
            1 => ['label' => 'emergency', 'display' => 'Kecemasan', 'color' => 'danger',
'wait_minutes' => 0],
            2 => ['label' => 'urgent', 'display' => 'Segera', 'color' => 'warning', 'wait_minutes' =>
10],
            3 => ['label' => 'semi_urgent', 'display' => 'Separa Segera', 'color' => 'info',
'wait_minutes' => 30],
            4 => ['label' => 'standard', 'display' => 'Standard', 'color' => 'primary', 'wait_minutes'
=> 60],
            5 => ['label' => 'non_urgent', 'display' => 'Tidak Segera', 'color' => 'secondary',
'wait_minutes' => 120],
        ],
    ],

    /*
    |--------------------------------------------------------------------------
    | Diagnosis Configuration
    |--------------------------------------------------------------------------
    */
    'diagnosis' => [
        'enabled' => true,
        'model_version' => 'v1.0',
        'max_suggestions' => 5,
        'min_confidence' => 20, // Minimum confidence to show
    ],

    /*
    |--------------------------------------------------------------------------
    | Drug Interaction Configuration
    |--------------------------------------------------------------------------
```

```
*/
'drug_check' => [
    'enabled' => true,
    'model_version' => 'v1.0',
    'data_source' => 'mims', // mims, drugbank, custom

    'severity_actions' => [
        'severe' => 'block', // block, warn, info
        'moderate' => 'warn',
        'mild' => 'info',
    ],
],

/*
|--------------------------------------------------------------------------
| Confidence Thresholds
|--------------------------------------------------------------------------
*/
'confidence' => [
    'high' => 85,
    'medium' => 70,
    'low' => 0,

    'escalation_threshold' => 70, // Below this, escalate to senior
    'hide_threshold' => 20, // Below this, don't show
],

/*
|--------------------------------------------------------------------------
| Red Flag Configuration
|--------------------------------------------------------------------------
*/
'red_flags' => [
    'enabled' => true,
    'acknowledgement_timeout_minutes' => 5,
    'escalation_enabled' => true,
    'audio_alert' => true,
],

/*
|--------------------------------------------------------------------------
| Human-in-the-Loop Configuration
|--------------------------------------------------------------------------
*/
'human_in_loop' => [
    'mandatory_review' => true,
    'allow_auto_accept' => false, // Never auto-accept
    'require_justification_on_reject' => true,
    'min_justification_length' => 10,
],

/*
|--------------------------------------------------------------------------
| Feedback Configuration
|--------------------------------------------------------------------------
*/
```

```
    'feedback' => [
        'enabled' => true,
        'collect_outcomes' => true,
        'de_identify_for_training' => true,
        'de_identification_delay_days' => 30,
    ],

    /*
    |--------------------------------------------------------------------------
    | EMR Summary Configuration
    |--------------------------------------------------------------------------
    */
    'summary' => [
        'enabled' => true,
        'recent_visits_months' => 6,
        'include_vitals_trend' => true,
        'include_lab_trend' => true,
        'highlight_critical' => true,
    ],

    /*
    |--------------------------------------------------------------------------
    | Audit Configuration
    |--------------------------------------------------------------------------
    */
    'audit' => [
        'log_all_predictions' => true,
        'log_all_reviews' => true,
        'retention_years' => 7,
    ],
];
```

File: `config/ai_governance.php`

```
<?php

return [
    /*
    |--------------------------------------------------------------------------
    | AI Ethics & Governance
    |--------------------------------------------------------------------------
    */
    'ethics' => [
        'bias_monitoring_enabled' => true,
        'fairness_metrics' => ['demographic_parity', 'equalized_odds'],
        'protected_attributes' => ['age', 'gender', 'ethnicity'],
    ],

    /*
    |--------------------------------------------------------------------------
    | Model Versioning
    |--------------------------------------------------------------------------
    */
    'versioning' => [
        'require_changelog' => true,
        'require_performance_metrics' => true,
```

```
    'allow_rollback' => true,
    'max_versions_kept' => 10,
],

/*
|--------------------------------------------------------------------------
| Performance Monitoring
|--------------------------------------------------------------------------
*/
'performance' => [
    'metrics' => [
        'accuracy',
        'precision',
        'recall',
        'f1_score',
        'auc_roc',
    ],
    'alert_thresholds' => [
        'accuracy_drop' => 5, // Alert if drops by 5%
        'latency_increase' => 50, // Alert if increases by 50%
    ],
    'monitoring_interval_minutes' => 60,
],

/*
|--------------------------------------------------------------------------
| Incident Management
|--------------------------------------------------------------------------
*/
'incidents' => [
    'require_root_cause' => true,
    'escalation_matrix' => [
        'critical' => ['admin', 'clinical_director'],
        'high' => ['admin'],
        'medium' => ['ai_admin'],
        'low' => ['ai_admin'],
    ],
    'resolution_sla_hours' => [
        'critical' => 4,
        'high' => 24,
        'medium' => 72,
        'low' => 168, // 1 week
    ],
],

/*
|--------------------------------------------------------------------------
| Reporting
|--------------------------------------------------------------------------
*/
'reporting' => [
    'daily_summary' => true,
    'weekly_performance_report' => true,
    'monthly_governance_report' => true,
    'report_recipients' => [], // Email addresses
],
```

```
    /*
    |--------------------------------------------------------------------------
    | Data Privacy (PDPA)
    |--------------------------------------------------------------------------
    */
    'privacy' => [
        'processing_location' => 'on_premise',
        'encryption_at_rest' => true,
        'encryption_in_transit' => true,
        'data_minimization' => true,
        'purpose_limitation' => true,
        'retention_policy_years' => 7,
    ],
];
```

5.6 Routes (Route Attributes)

Route Summary:

Method	URI	Name	Description
GET	`/admin/ai/triage`	admin.ai.triage.index	Triage dashboard
POST	`/admin/ai/triage/assess`	admin.ai.triage.assess	Run AI triage assessment
POST	`/admin/ai/triage/{result}/override`	admin.ai.triage.override	Override triage result
GET	`/admin/ai/summary/{pesakit}`	admin.ai.summary.show	Get EMR summary
POST	`/admin/ai/summary/{pesakit}/refresh`	admin.ai.summary.refresh	Refresh EMR summary
GET	`/admin/ai/diagnosis/{encounter}`	admin.ai.diagnosis.show	Get diagnosis suggestions
POST	`/admin/ai/diagnosis/{prediction}/review`	admin.ai.diagnosis.review	Review diagnosis suggestion
GET	`/admin/ai/drug-check`	admin.ai.drug-check.index	Drug check interface
POST	`/admin/ai/drug-check/analyze`	admin.ai.drug-check.analyze	Analyze drug interactions
POST	`/admin/ai/drug-check/{alert}/acknowledge`	admin.ai.drug-check.acknowledge	Acknowledge drug alert
POST	`/admin/ai/drug-check/{alert}/override`	admin.ai.drug-check.override	Override drug alert
GET	`/admin/ai/red-flags`	admin.ai.red-flags.index	Red flag alerts
POST	`/admin/ai/red-flags/{alert}/acknowledge`	admin.ai.red-flags.acknowledge	Acknowledge red flag
POST	`/admin/ai/red-flags/{alert}/resolve`	admin.ai.red-flags.resolve	Resolve red flag

GET	`/admin/ai/feedback`	admin.ai.feedback.index	Feedback dashboard
POST	`/admin/ai/feedback`	admin.ai.feedback.store	Submit feedback
GET	`/admin/ai/governance`	admin.ai.governance.index	Governance dashboard
GET	`/admin/ai/governance/performance`	admin.ai.governance.performance	Performance metrics
GET	`/admin/ai/governance/incidents`	admin.ai.governance.incidents	Incident list
POST	`/admin/ai/governance/incidents`	admin.ai.governance.incidents.store	Report incident
GET	`/admin/ai/governance/models`	admin.ai.governance.models	Model versions
POST	`/admin/ai/governance/models/{version}/activate`	admin.ai.governance.models.activate	Activate model
POST	`/admin/ai/governance/models/{version}/rollback`	admin.ai.governance.models.rollback	Rollback model

---

6. Workflow dan User Flow

6.1 Triage Workflow

```
[Jururawat] → Pilih pesakit dari queue
    ↓
[Sistem] → Auto-load patient history
    ↓
[Jururawat] → Input chief complaint dan symptoms
    ↓
[Sistem] → Capture vital signs (manual/auto dari device)
    ↓
[AI Engine] → Analyze symptoms + vitals + history
    ↓
[AI Engine] → Calculate severity score (1-5)
    ↓
[AI Engine] → Detect red flags
    ↓ (Red flags detected?)
    ├── Yes → [Sistem] Trigger red flag alert (visual + audio)
    │           ↓
    │         [Jururawat] → Acknowledge dan escalate
    │           ↓
    │         [Doktor] → Review immediately
    │
    └── No → [Sistem] Display triage result dengan reasoning
              ↓
            [Jururawat] → Review dan confirm/override
              ↓
            [Sistem] → Assign ke queue mengikut severity
              ↓
            [Sistem] → Log audit trail
```

6.2 Clinical Decision Support Workflow

```
[Doktor] → Open consultation untuk pesakit
    ↓
[Sistem] → Auto-generate EMR Summary (async)
    ↓
[Doktor] → View EMR Summary panel
    ↓
[Doktor] → Document current symptoms dan findings
    ↓
[AI Engine] → Generate differential diagnosis
    ↓
[Sistem] → Display suggestions dengan:
           - Confidence scores
           - Reasoning chain
           - Supporting evidence
           - Recommended investigations
    ↓
[Doktor] → Review setiap suggestion
    ↓
[Doktor] → Accept / Reject / Modify setiap suggestion
    ↓ (If reject/modify)
    └── [Sistem] → Require justification
          ↓
        [Sistem] → Log untuk feedback loop
    ↓
[Doktor] → Select final diagnosis
    ↓
[Sistem] → Suggest treatment options
    ↓
[Doktor] → Prescribe medications
    ↓
[AI Engine] → Check drug interactions
    ↓ (Interactions detected?)
    ├── Severe → [Sistem] Block prescription, show alert
    │             ↓
    │           [Doktor] → Override dengan justification ATAU choose alternative
    │
    ├── Moderate → [Sistem] Show warning
    │               ↓
    │             [Doktor] → Acknowledge dan proceed
    │
    └── Mild → [Sistem] Show info badge
    ↓
[Sistem] → Save prescription
    ↓
[Sistem] → Log audit trail
```

6.3 Red Flag Escalation Workflow

```
[AI Engine] → Detect red flag
    ↓
[Sistem] → Create red flag alert
    ↓
[Sistem] → Display prominent alert (visual + audio)
    ↓
[Start Timer] → 5 minute acknowledgement timeout
```

```
    ↓
[Clinician] → Acknowledge alert?
    ├── Yes (within 5 min) →
    │     ↓
    │   [Clinician] → Take action
    │     ↓
    │   [Clinician] → Document resolution
    │     ↓
    │   [Sistem] → Close alert, log audit
    │
    └── No (timeout) →
          ↓
        [Sistem] → Escalate to senior doctor
          ↓
        [Sistem] → Send notification (in-app + SMS)
          ↓
        [Senior Doctor] → Acknowledge dan take over
```

6.4 Feedback Loop Workflow

```
[Clinician] → Rate AI prediction (helpful/not helpful/incorrect)
    ↓
[Sistem] → Store feedback with prediction_id
    ↓
[Clinician] → (Optional) Record actual outcome
    ↓
[Sistem] → Store outcome data
    ↓
[Background Job] → De-identify data after 30 days
    ↓
[Background Job] → Include in training dataset
    ↓
[AI Team] → Periodic model retraining
    ↓
[Admin] → Review model performance
    ↓
[Admin] → Deploy new model version (if improved)
    ↓
[Sistem] → Track new version performance
```

6.5 State Management

Prediction Status Flow:

```
[Created] → [Pending Review] → [Accepted]
                    ↓
               [Rejected]
                    ↓
               [Modified]
```

Red Flag Alert Status Flow:

```
[Triggered] → [Acknowledged] → [Resolved]
      ↓              ↓
[Escalated]    [False Positive]
      ↓
```

```
[Acknowledged by Senior]
      ↓
[Resolved/Referred]
```

Drug Alert Status Flow:

```
[Detected] → [Acknowledged] → [Proceeded]
      ↓
[Overridden (with justification)]
      ↓
[Alternative Selected]
```

---

7. Keperluan UI/UX

7.1 Layout

- **Jenis Halaman**: Embedded widgets dalam EMR interface + dedicated governance dashboard
- **Navigation**: AI panel sebagai sidebar/widget dalam consultation screen

AI Integration Points:

```
📁 Consultation Screen
├── 🤖 AI Summary Panel (collapsible sidebar)
│   ├── Problem List
│   ├── Current Medications
│   ├── Allergies (highlighted)
│   ├── Vital Signs Trend
│   └── Recent Visits
├── 🎯 Triage Widget (for nurses)
│   ├── Symptom Input
│   ├── Severity Score Display
│   └── Red Flag Alerts
├── 💊 Diagnosis Suggestions (inline)
│   ├── Differential List
│   ├── Confidence Scores
│   └── Accept/Reject Buttons
└── ⚠️ Drug Interaction Alerts (modal/toast)
    ├── Alert Details
    ├── Alternatives
    └── Override Option

📁 AI Governance (Admin)
├── 📊 Performance Dashboard
├── 🔄 Model Versions
├── 🚨 Incidents
├── 📈 Analytics
└── ⚙️ Settings
```

7.2 Bootstrap 5 + CoreUI Components

- ☑ **Card** - Summary panels, diagnosis cards, alert cards
- ☑ **Alert** - Red flags (danger), warnings (warning), info (info)
- ☑ **Badge** - Confidence levels, severity badges, status badges
- ☑ **Progress** - Confidence bars, loading indicators
- ☑ **Modal** - Drug interaction details, override justification
- ☑ **Toast** - Non-blocking notifications

- ☑ **Button Group** - Accept/Reject/Modify actions
- ☑ **Collapse** - Expandable reasoning chains
- ☑ **Tooltip** - Hover explanations
- ☑ **Charts** - Vital signs trends, performance metrics (Chart.js)

7.3 Key UI Components

AI Summary Panel:

- Collapsible sidebar attached to consultation screen
- Color-coded sections (allergies in red, medications in blue)
- Mini-charts untuk vital signs trends
- Expand/collapse untuk each section
- "Last updated" timestamp

Triage Result Card:

- Large severity badge (color-coded)
- Countdown timer untuk wait time
- Red flag indicators (if any)
- Override button dengan justification modal
- Reasoning chain (collapsible)

Diagnosis Suggestion Card:

- Rank number dan ICD code
- Confidence bar (visual)
- Supporting evidence bullets
- "Explain" button untuk reasoning chain
- Accept/Reject buttons
- Link ke clinical guidelines

Drug Alert Modal:

- Severity indicator (color-coded header)
- Interaction description
- Clinical significance
- Recommended alternatives (clickable to select)
- Override dengan justification text area
- "Learn more" link

Red Flag Alert Banner:

- Full-width banner at top of screen
- Pulsing animation untuk critical
- Clear action buttons
- Timer showing seconds since triggered
- Audio icon (click to mute)

7.4 Icons

Custom AI Icons:

- `heroicon-o-cpu-chip` - AI/ML features
- `heroicon-o-light-bulb` - Suggestions
- `heroicon-o-exclamation-triangle` - Warnings
- `heroicon-o-shield-exclamation` - Red flags
- `heroicon-o-check-circle` - Accepted
- `heroicon-o-x-circle` - Rejected
- `heroicon-o-arrow-path` - Processing

- `heroicon-o-chart-bar` - Analytics
- `heroicon-o-beaker` - Investigations
- `heroicon-o-document-text` - Guidelines

7.5 Responsive Design

- **Mobile Support**: Limited - governance dashboard only
- **Tablet Support**: Ya - full functionality
- **Desktop Priority**: Primary interface untuk clinical use

---

8. Keperluan Keselamatan

8.1 Authentication & Authorization

- **Authentication**: Laravel Breeze (inherited from main system)
- **Middleware**: `auth`, `ai.consent`, `ai.log`
- **Role-based Access**: Doktor, Jururawat, Admin dengan permissions berbeza
- **MMC Verification**: Doktor mesti MMC-registered untuk clinical decision support

8.2 Data Protection (PDPA Compliance)

- **On-Premise Processing**: Semua AI processing dalam server klinik, tiada data ke cloud
- **Encryption at Rest**: AES-256 untuk prediction data
- **Encryption in Transit**: TLS 1.3 untuk internal API
- **Data Minimization**: Hanya collect data yang diperlukan untuk predictions
- **Purpose Limitation**: Data hanya digunakan untuk clinical decision support
- **Consent**: Pesakit consent untuk AI-assisted care (dalam general consent form)
- **Data Retention**: 7 tahun untuk audit, de-identified untuk training

8.3 AI-Specific Security

- **Model Security**: Models stored encrypted, access controlled
- **Input Validation**: Sanitize semua input sebelum hantar ke AI engine
- **Output Validation**: Validate AI output sebelum display
- **Adversarial Protection**: Basic protection against adversarial inputs
- **Audit Trail**: Complete logging untuk semua AI interactions

8.4 Input Validation & Security

- **CSRF Protection**: Semua POST requests
- **SQL Injection Prevention**: Eloquent ORM
- **XSS Prevention**: Blade escaping
- **Rate Limiting**: Limit AI API calls per user

---

9. Keperluan Prestasi

9.1 Response Time

- **Triage Assessment**: < 3 saat
- **EMR Summary Generation**: < 2 saat
- **Diagnosis Suggestions**: < 5 saat
- **Drug Interaction Check**: < 2 saat
- **Red Flag Detection**: < 1 saat (real-time)

9.2 Scalability

- **Concurrent Users**: 20-30 clinicians simultaneously
- **AI Engine**: Dapat handle 100 requests/minute
- **Caching**: Cache knowledge base dalam Redis
- **Queue Processing**: Async processing untuk non-critical tasks

- **Model Optimization**: Optimized models untuk inference speed

9.3 Availability

- **AI Engine Uptime**: > 99.5%
- **Fallback Mode**: Manual mode available jika AI engine down
- **Health Checks**: Periodic health checks dengan auto-restart

---

10. Keperluan Ujian

10.1 Unit Testing

File: `tests/Unit/Services/TriageServiceTest.php`

- [ ] **Test**: Calculate severity score correctly untuk different symptom combinations
- [ ] **Test**: Detect red flags correctly
- [ ] **Test**: Handle missing vital signs gracefully
- [ ] **Test**: Override logic works correctly

File: `tests/Unit/Services/DrugInteractionServiceTest.php`

- [ ] **Test**: Detect drug-drug interactions correctly
- [ ] **Test**: Detect drug-allergy interactions
- [ ] **Test**: Severity classification is correct
- [ ] **Test**: Alternative suggestions are relevant

10.2 Feature Testing

File: `tests/Feature/AiTriageTest.php`

- [ ] **Test**: Nurse can perform AI triage
- [ ] **Test**: Doctor cannot override without justification
- [ ] **Test**: Red flag triggers alert
- [ ] **Test**: Audit log is created

File: `tests/Feature/AiDiagnosisTest.php`

- [ ] **Test**: Doctor can view diagnosis suggestions
- [ ] **Test**: Accept/reject workflow works
- [ ] **Test**: Feedback is recorded
- [ ] **Test**: Low confidence triggers escalation

File: `tests/Feature/AiDrugCheckTest.php`

- [ ] **Test**: Severe interaction blocks prescription
- [ ] **Test**: Override requires justification
- [ ] **Test**: Alternatives are displayed

10.3 Integration Testing

- [ ] **Test**: Laravel ↔ Python AI Engine communication
- [ ] **Test**: Knowledge base integration
- [ ] **Test**: EMR data retrieval untuk summary
- [ ] **Test**: Real-time alert delivery

10.4 AI Model Testing

- [ ] **Test**: Model accuracy meets threshold (>85% untuk high-confidence)

- [x] **Test**: Model bias testing across demographics
- [x] **Test**: Edge case handling
- [x] **Test**: Explainability outputs are coherent

10.5 User Acceptance Testing (UAT)

Scenario 1: Nurse Triage Workflow

- Steps: Input symptoms → Get severity → Acknowledge red flag
- Expected Result: Correct severity, alert triggered, logged

Scenario 2: Doctor Diagnosis Review

- Steps: View suggestions → Review reasoning → Accept/reject
- Expected Result: Decision recorded, audit trail created

Scenario 3: Drug Interaction Override

- Steps: Prescribe → See severe alert → Override with justification
- Expected Result: Justification required, prescription proceeds

Scenario 4: Red Flag Escalation

- Steps: Red flag triggered → No acknowledge → Auto-escalate
- Expected Result: Escalation notification sent within 5 minutes

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11. Langkah Implementasi

11.1 Fasa 1: Infrastructure Setup (Minggu 1-2)

- [ ] Setup Python AI Engine (FastAPI)
- [ ] Configure internal communication Laravel ↔ Python
- [ ] Setup Redis untuk caching
- [ ] Create database migrations untuk AI tables
- [ ] Setup logging infrastructure
- [ ] Configure encryption untuk sensitive data

11.2 Fasa 2: Knowledge Base (Minggu 3-4)

- [ ] Import symptom ontology
- [ ] Import drug database (MIMS equivalent)
- [ ] Import clinical guidelines (MOH, WHO)
- [ ] Import ICD-10 codes
- [ ] Setup knowledge base versioning
- [ ] Create admin interface untuk knowledge base management

11.3 Fasa 3: AI Models Development (Minggu 5-8)

- [ ] Develop triage rule engine
- [ ] Train triage ML model (XGBoost)
- [ ] Develop diagnosis suggestion model
- [ ] Develop drug interaction checker
- [ ] Implement explainability (SHAP)
- [ ] Validate models dengan clinical data
- [ ] Package models untuk deployment

11.4 Fasa 4: Laravel Integration (Minggu 9-11)

- [ ] Create AI Services (Triage, Diagnosis, DrugCheck)
- [ ] Create AI Engine Client
- [ ] Create Controllers dengan Route Attributes
- [ ] Create FormRequest validations
- [ ] Create Repositories
- [ ] Create Models

11.5 Fasa 5: UI Development (Minggu 12-14)

- [ ] Create triage form dan result views
- [ ] Create EMR summary panel
- [ ] Create diagnosis suggestion cards
- [ ] Create drug alert modals
- [ ] Create red flag alert banners
- [ ] Create feedback forms
- [ ] Integrate dengan EMR interface

11.6 Fasa 6: Governance Dashboard (Minggu 15-16)

- [ ] Create performance metrics dashboard
- [ ] Create model version management
- [ ] Create incident reporting system
- [ ] Create audit log viewer
- [ ] Create analytics reports

11.7 Fasa 7: Testing & Validation (Minggu 17-19)

- [ ] Unit tests untuk all services
- [ ] Feature tests untuk all workflows
- [ ] Integration tests dengan AI engine
- [ ] AI model validation dengan clinical experts
- [ ] Security testing
- [ ] Performance testing
- [ ] UAT dengan doctors dan nurses

11.8 Fasa 8: Deployment & Training (Minggu 20)

- [ ] Deploy AI engine ke production server
- [ ] Deploy Laravel updates
- [ ] Clinical staff training
- [ ] Admin training (governance)
- [ ] Soft launch dengan limited users
- [ ] Monitor closely
- [ ] Full rollout

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12. Kriteria Kejayaan

12.1 Clinical Metrics

- **Triage Accuracy**: > 90% agreement dengan senior clinician
- **Red Flag Sensitivity**: 100% (zero missed critical cases)
- **Drug Interaction Detection**: > 99% untuk severe interactions
- **Diagnosis Suggestion Utility**: > 80% rated as "helpful" oleh doctors

12.2 Operational Metrics

- **Triage Time Reduction**: 30% faster than manual
- **Clinician Adoption**: > 80% using AI features regularly
- **Override Rate**: < 20% (indicates AI accuracy)
- **Critical Alert Response Time**: < 5 minutes average

12.3 Technical Metrics

- **AI Engine Uptime**: > 99.5%
- **Response Time**: < 5 saat untuk all predictions
- **Error Rate**: < 1% API errors
- **Model Performance**: Accuracy, Precision, Recall > 85%

12.4 Safety Metrics

- **Zero Patient Harm**: No harm attributable to AI recommendations
- **Incident Response**: All incidents resolved within SLA
- **Audit Compliance**: 100% actions logged

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13. Risks & Mitigation

Risk	Likelihood	Impact	Mitigation
AI gives wrong recommendation	Medium	Critical	Human-in-the-loop mandatory, confidence thresholds, escalation
Clinicians over-rely on AI	Medium	High	Training, clear disclaimers, regular audits
Model bias against demographics	Low	High	Bias monitoring, diverse training data, regular testing
AI engine downtime	Low	Medium	Fallback to manual mode, health monitoring, auto-restart
Data privacy breach	Low	Critical	On-premise processing, encryption, access controls
Resistance from clinicians	Medium	Medium	Gradual rollout, training, demonstrate value
Knowledge base outdated	Medium	Medium	Version control, update notifications, review process
Red flag missed	Low	Critical	Multiple detection layers, high sensitivity tuning
Integration issues dengan EMR	Medium	Medium	Thorough testing, API versioning, fallback modes
Regulatory concerns	Low	High	Clear disclaimers, audit trails, human oversight

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14. Dependencies

14.1 External Packages (Laravel)

- ☑ **guzzlehttp/guzzle**: ^7.0 - HTTP client untuk AI Engine communication
- ☑ **predis/predis**: ^2.0 - Redis client untuk caching
- ☑ **laravel/horizon**: ^5.0 - Queue monitoring

14.2 Python AI Engine Dependencies

- ☑ **fastapi**: ^0.100 - API framework
- ☑ **scikit-learn**: ^1.3 - ML algorithms
- ☑ **xgboost**: ^2.0 - Gradient boosting

- ☑ **shap**: ^0.44 - Explainability
- ☑ **pandas**: ^2.0 - Data manipulation
- ☑ **numpy**: ^1.24 - Numerical computing
- ☑ **pydantic**: ^2.0 - Data validation

14.3 Related Features/Modules

Bergantung Kepada:

- Modul EMR (patient data, encounters)
- Modul Pendaftaran (patient demographics)
- Modul Farmasi (drug data)
- Modul Tetapan & Keselamatan (authentication, audit)

Memberi Impak Kepada:

- Semua clinical workflows (triage, consultation)
- Preskripsi workflow (drug checking)
- Queue management (prioritization)

14.4 Third-Party Data Sources

- ☑ **Drug Database**: MIMS Malaysia atau equivalent
- ☑ **Clinical Guidelines**: MOH Malaysia, WHO
- ☑ **ICD Codes**: ICD-10-CM/ICD-11

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15. Acceptance Criteria

15.1 Functional Acceptance

- ☑ AI triage provides severity score dengan 5 levels
- ☑ Red flags are detected dan trigger prominent alerts
- ☑ EMR summary is generated automatically
- ☑ Diagnosis suggestions include confidence scores dan reasoning
- ☑ Drug interactions are checked untuk all prescription combinations
- ☑ Severe drug interactions block prescription until override
- ☑ All AI recommendations require human review before action
- ☑ Override requires justification
- ☑ Feedback can be submitted untuk all predictions
- ☑ Low confidence predictions are escalated
- ☑ All AI interactions are logged untuk audit
- ☑ Governance dashboard shows performance metrics

15.2 Technical Acceptance

- ☑ AI Engine responds within performance targets
- ☑ All data processed on-premise (PDPA compliance)
- ☑ Encryption implemented untuk sensitive data
- ☑ All feature tests lulus
- ☑ Integration tests lulus
- ☑ No N+1 query problems
- ☑ Route cache cleared

15.3 Quality Acceptance

- [ ] AI model accuracy meets thresholds
- [ ] No bias detected across demographics
- [ ] UI/UX reviewed oleh clinical staff
- [ ] Responsive design berfungsi
- [ ] Accessibility considerations addressed

15.4 Documentation Acceptance

- [ ] PRD complete
- [ ] AI model documentation
- [ ] User guide untuk clinicians
- [ ] Admin guide untuk governance

15.5 Ethical Acceptance

- [ ] Clear disclaimers bahawa AI adalah decision support, bukan decision maker
- [ ] Transparency dalam reasoning (explainable AI)
- [ ] Human always in control
- [ ] Incident reporting mechanism available
- [ ] Regular performance reviews scheduled

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16. Lampiran

16.1 Manchester Triage System (MTS) Levels

Level	Nama	Warna	Masa Sasaran	Contoh Keadaan
1	Kecemasan	Merah	Segera (0 min)	Cardiac arrest, severe respiratory distress
2	Segera	Oren	10 minit	Chest pain, severe pain, high fever with rash
3	Separa Segera	Kuning	30 minit	Moderate pain, fever, vomiting
4	Standard	Hijau	60 minit	Minor injury, mild symptoms
5	Tidak Segera	Biru	120 minit	Chronic complaints, minor ailments

16.2 Red Flag Examples

Category	Red Flags
Cardiovascular	Chest pain, palpitations dengan syncope, severe hypertension
Respiratory	Severe dyspnea, stridor, cyanosis, SpO2 < 90%
Neurological	Stroke symptoms (FAST), sudden severe headache, altered consciousness
Abdominal	Rigid abdomen, significant GI bleeding
Pediatric	Limp child, non-blanching rash, severe dehydration
Obstetric	Heavy vaginal bleeding, severe pre-eclampsia signs
Mental Health	Active suicidal ideation, severe psychosis

16.3 Drug Interaction Severity Classification

Severity	Action	Example
Severe	Block prescription, require override	Warfarin + NSAIDs
Moderate	Warning, allow proceed	ACE-I + Potassium supplements
Mild	Information only	Metformin + alcohol

16.4 AI Ethics Principles Applied

1. **Beneficence**: AI designed to improve patient outcomes
2. **Non-maleficence**: Human oversight prevents AI harm
3. **Autonomy**: Patients informed about AI use, can opt-out
4. **Justice**: Bias monitoring ensures fair treatment
5. **Transparency**: Explainable AI, no black box
6. **Accountability**: Full audit trail, incident reporting

16.5 Change Log

Tarikh	Penulis	Perubahan
14 Januari 2026	AI Assistant	PRD awal dicipta

16.6 Approval

- ☐ **Product Owner**: _____ - _____
- ☐ **Tech Lead**: _____ - _____
- ☐ **Clinical Director**: _____ - _____
- ☐ **Pengurus Klinik**: _____ - _____
- ☐ **Data Protection Officer**: _____ - _____

Status Implementasi: Belum Bermula **Tarikh Selesai**: TBD

Catatan: Dokumen ini adalah living document dan akan dikemaskini mengikut keperluan semasa development. Modul AI memerlukan penglibatan pakar klinikal untuk validation dan testing. Semua AI recommendations adalah decision support sahaja dan bukan diagnosis muktamad.

Disclaimer

PENTING: Sistem AI ini adalah alat sokongan keputusan klinikal (Clinical Decision Support System) dan BUKAN pengganti kepada penilaian klinikal oleh profesional kesihatan yang berkelayakan. Semua cadangan AI mesti disemak dan disahkan oleh doktor atau jururawat sebelum sebarang tindakan klinikal diambil. Klinik dan pengguna bertanggungjawab sepenuhnya terhadap keputusan klinikal akhir.