Human-Machine Systems Engineering

Oregon State University
College of Engineering

Introduction & Example

A User-Centered Human-Machine Systems Engineering Process

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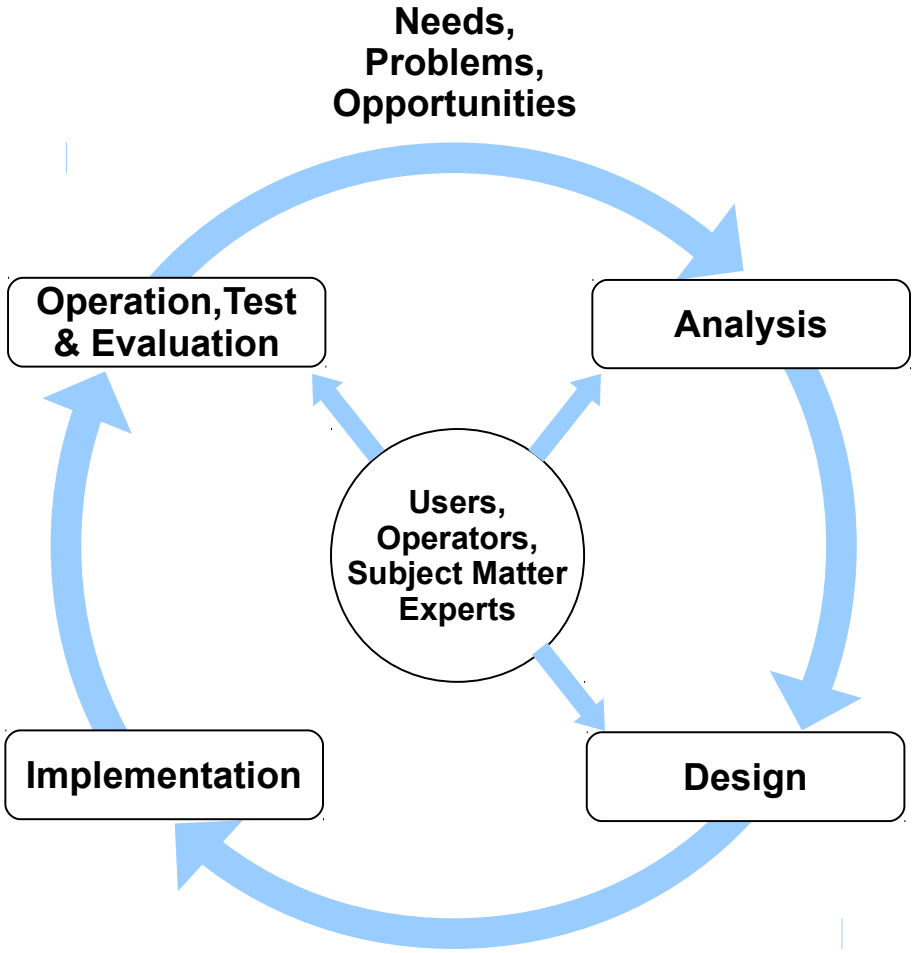
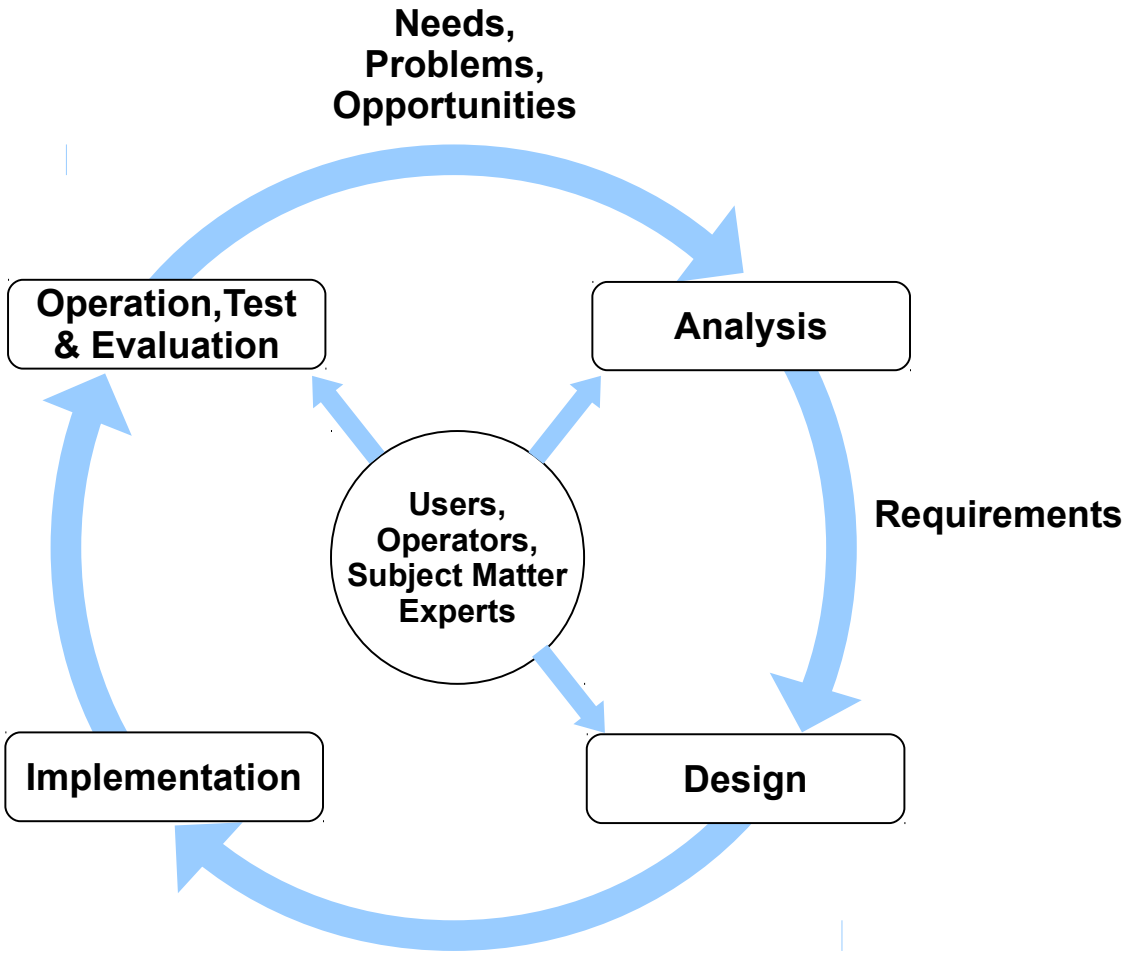
Needs,
Problems,
Opportunities

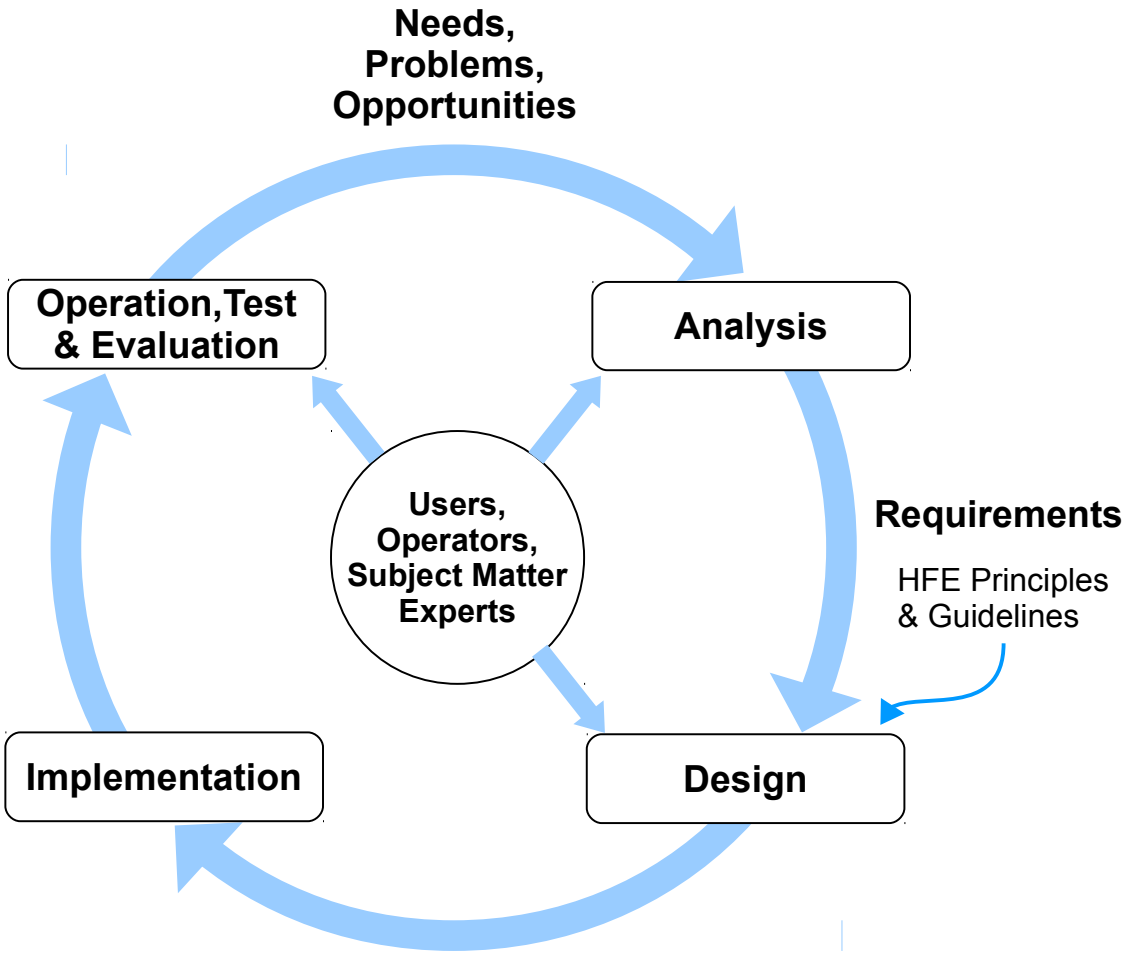
A User-Centered Human-Machine Systems Engineering Process



A User-Centered Human-Machine Systems Engineering Process



A User-Centered Human-Machine Systems Engineering Process



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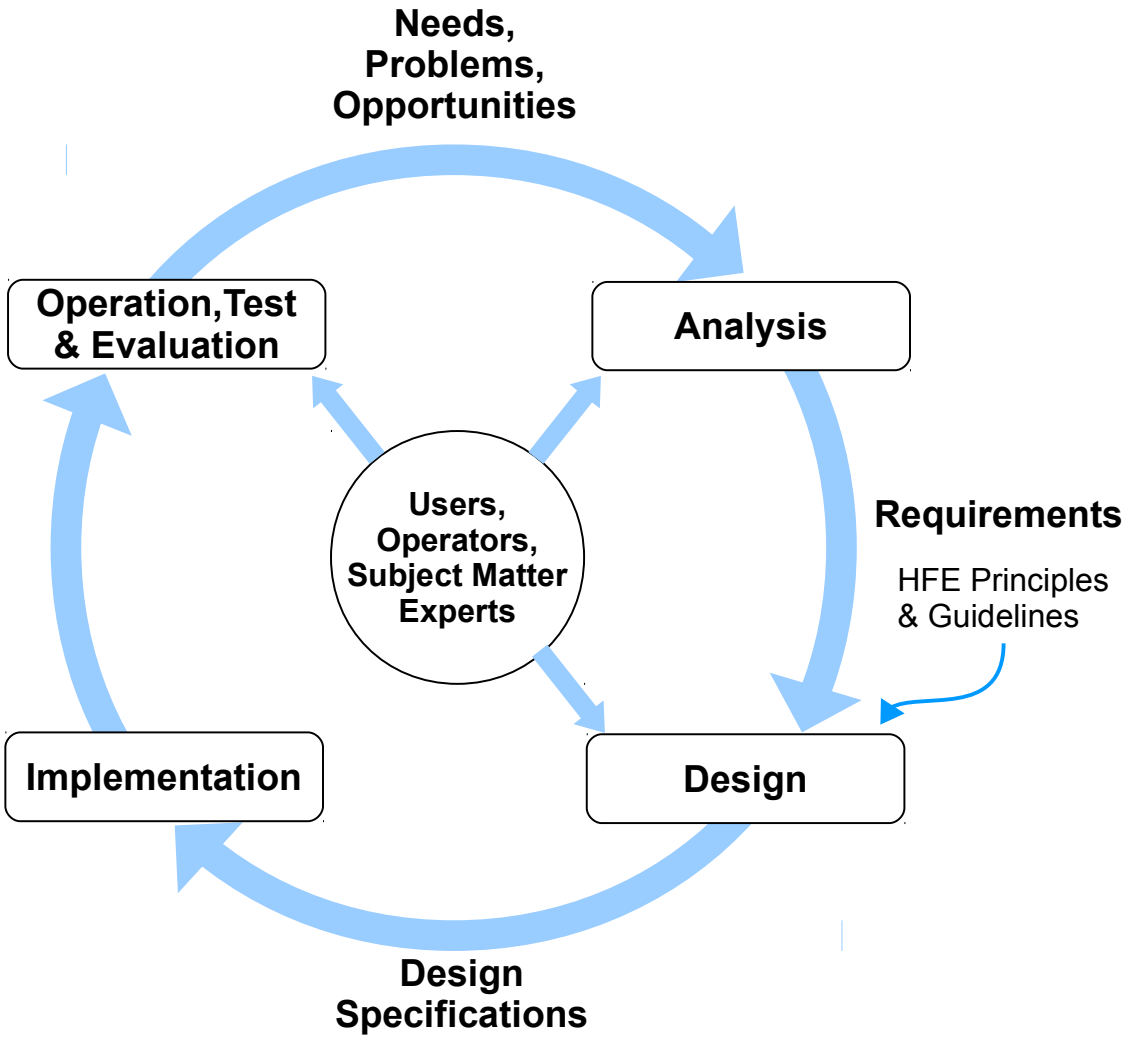

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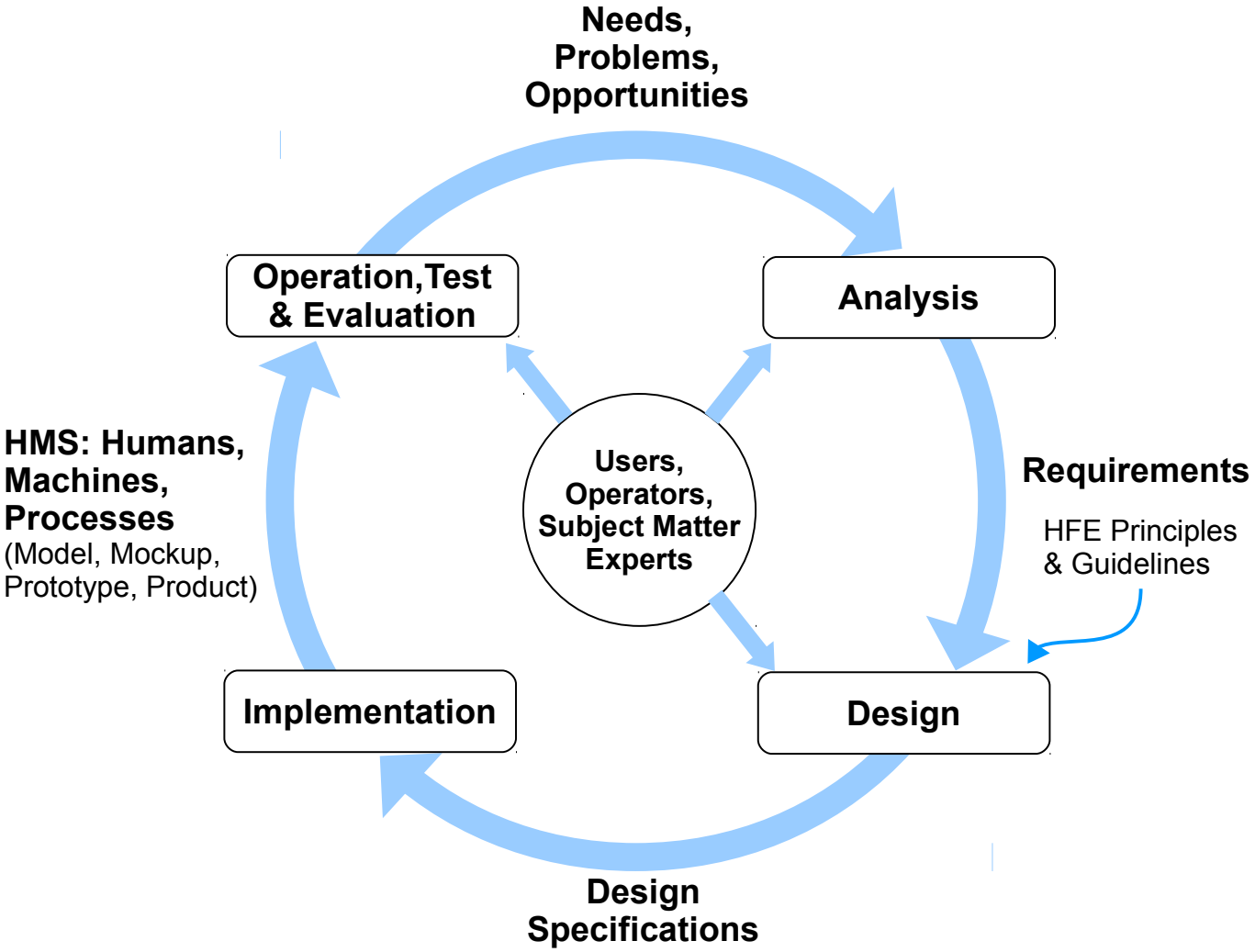

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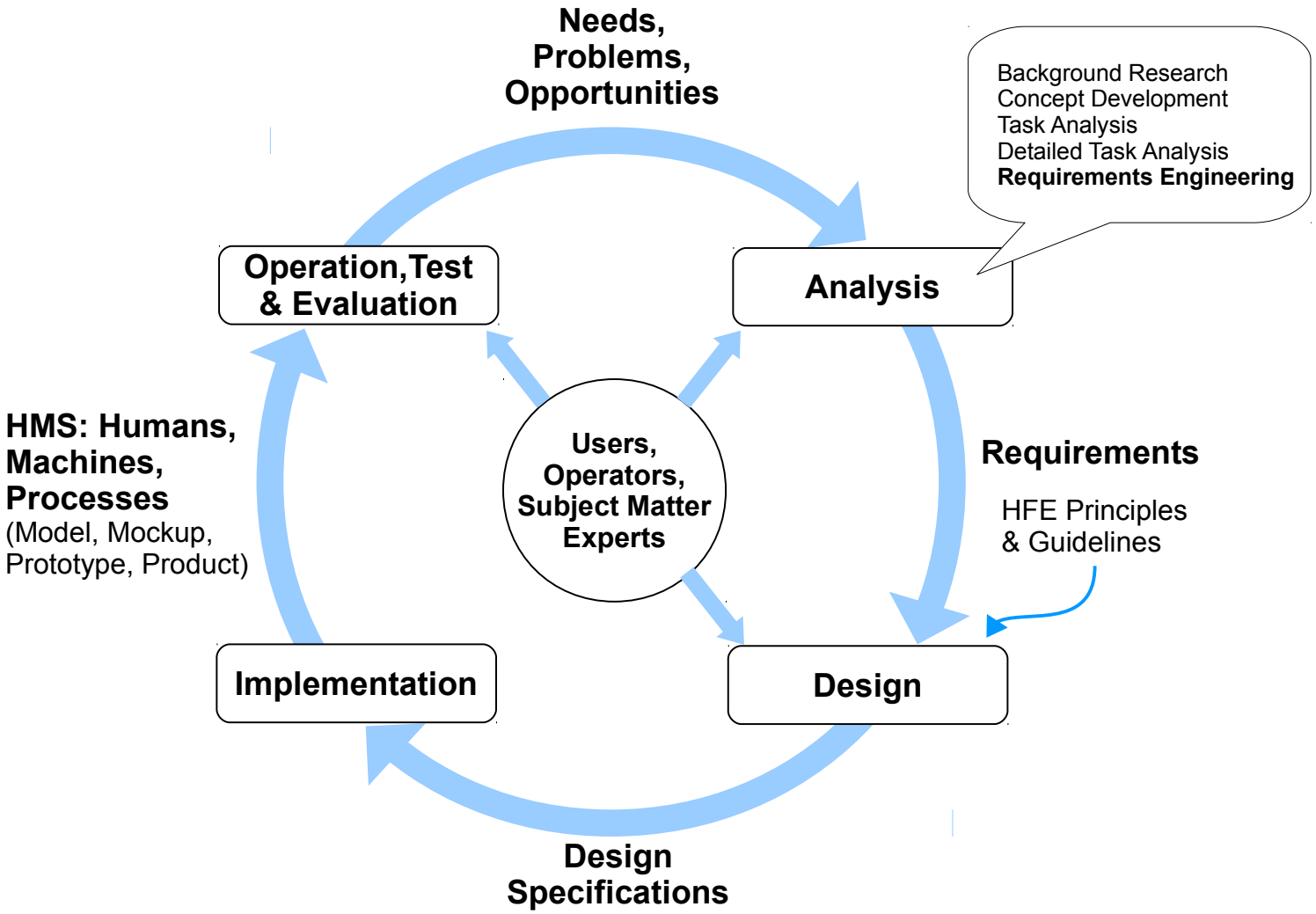

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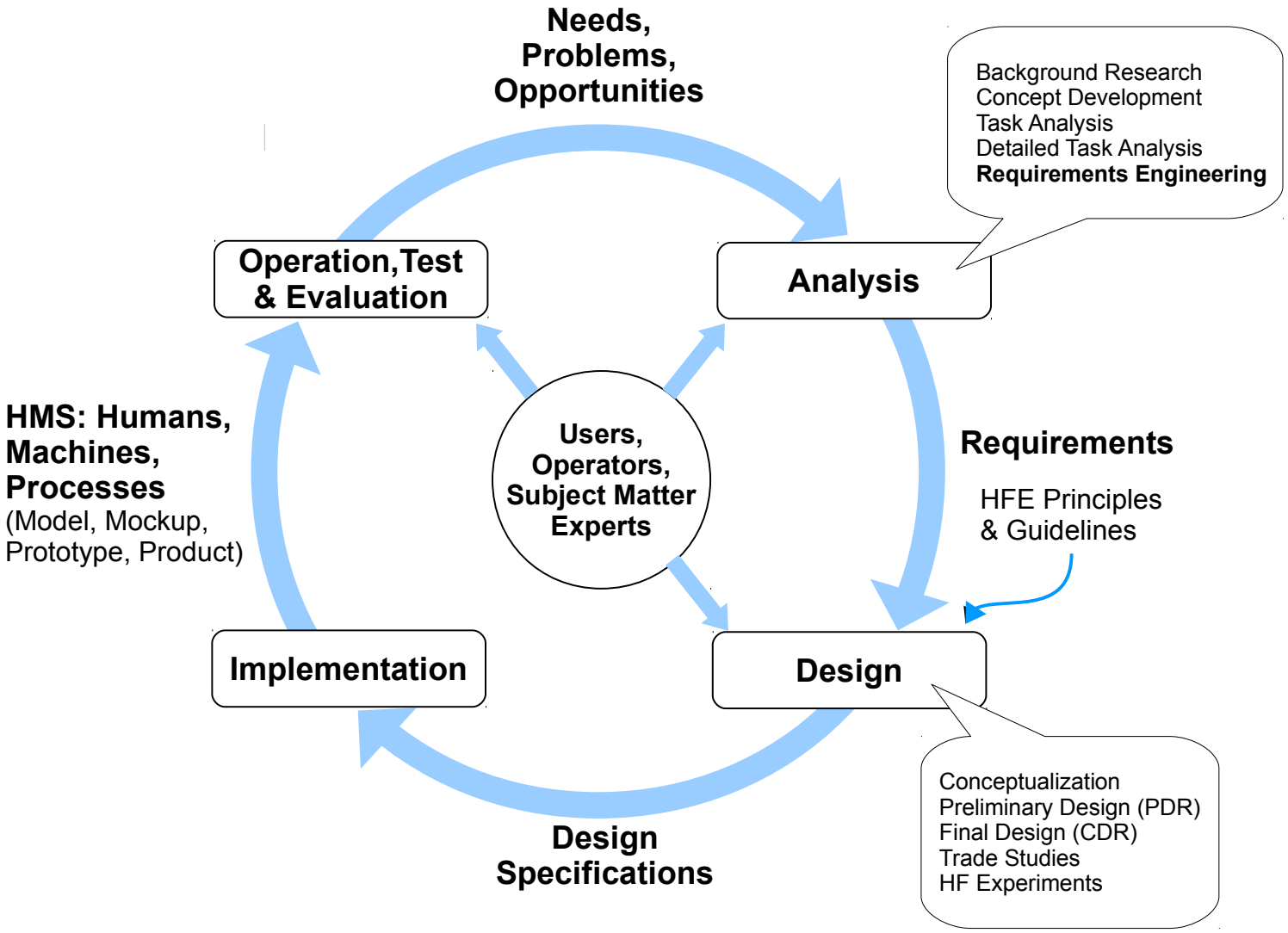

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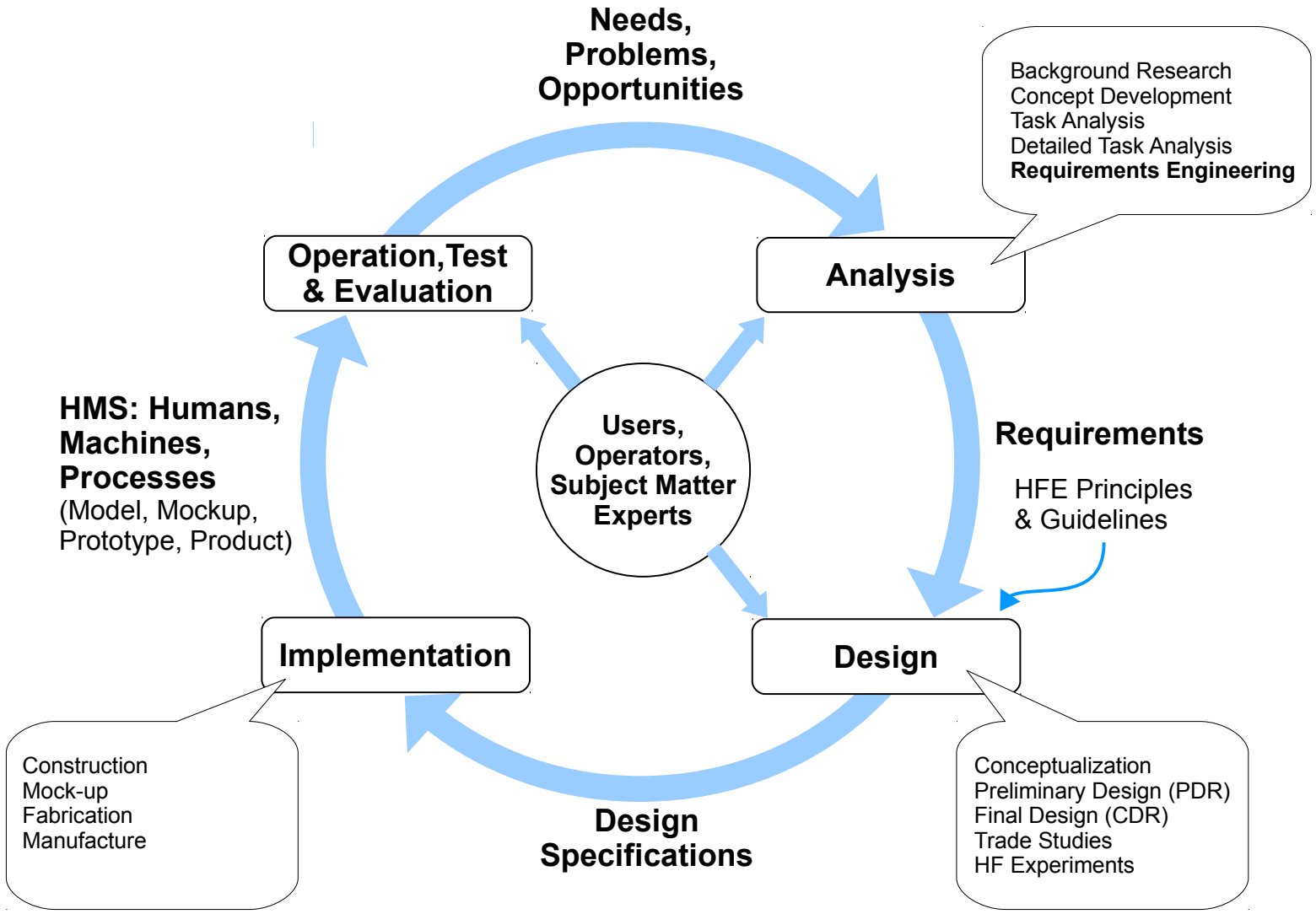

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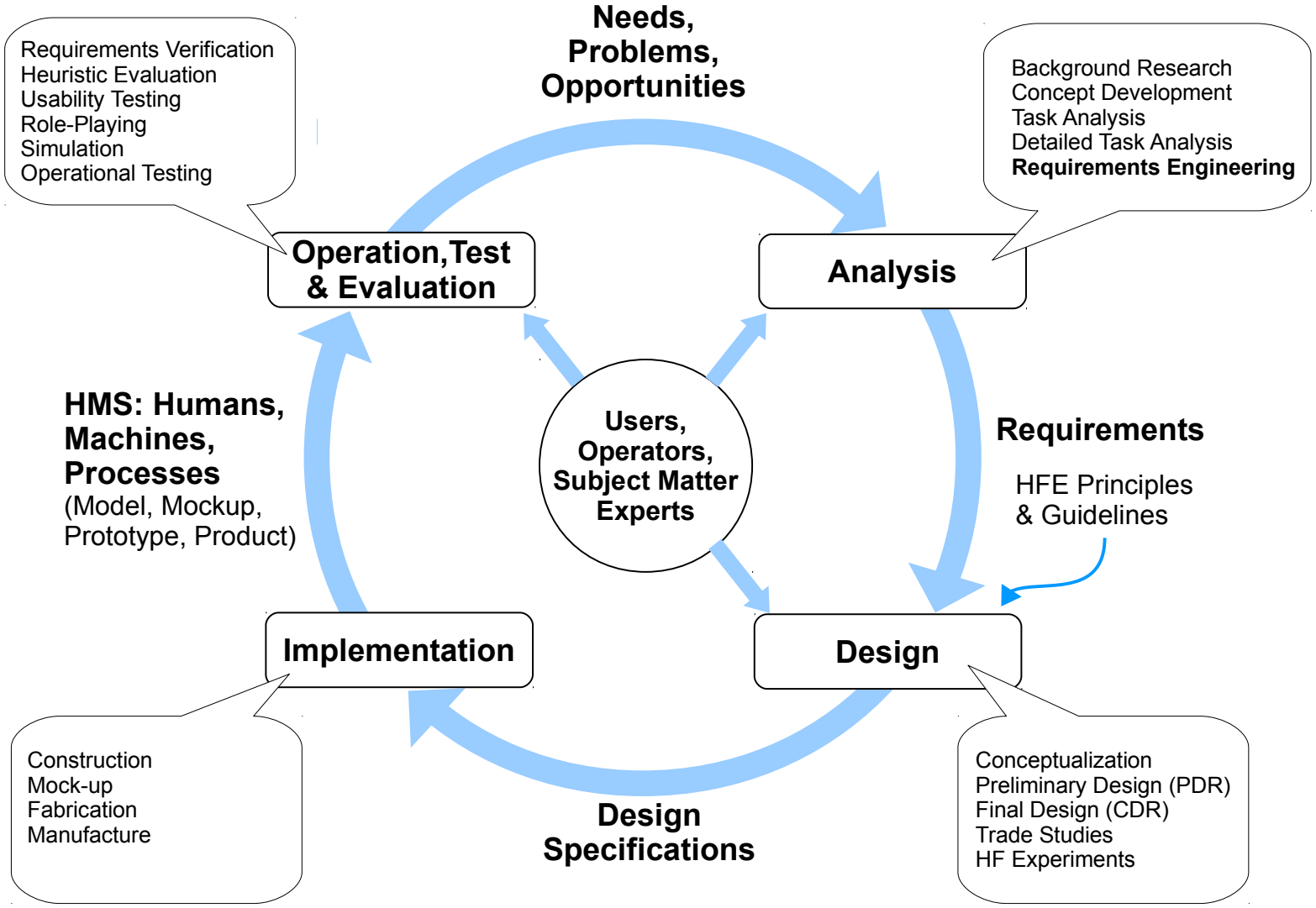

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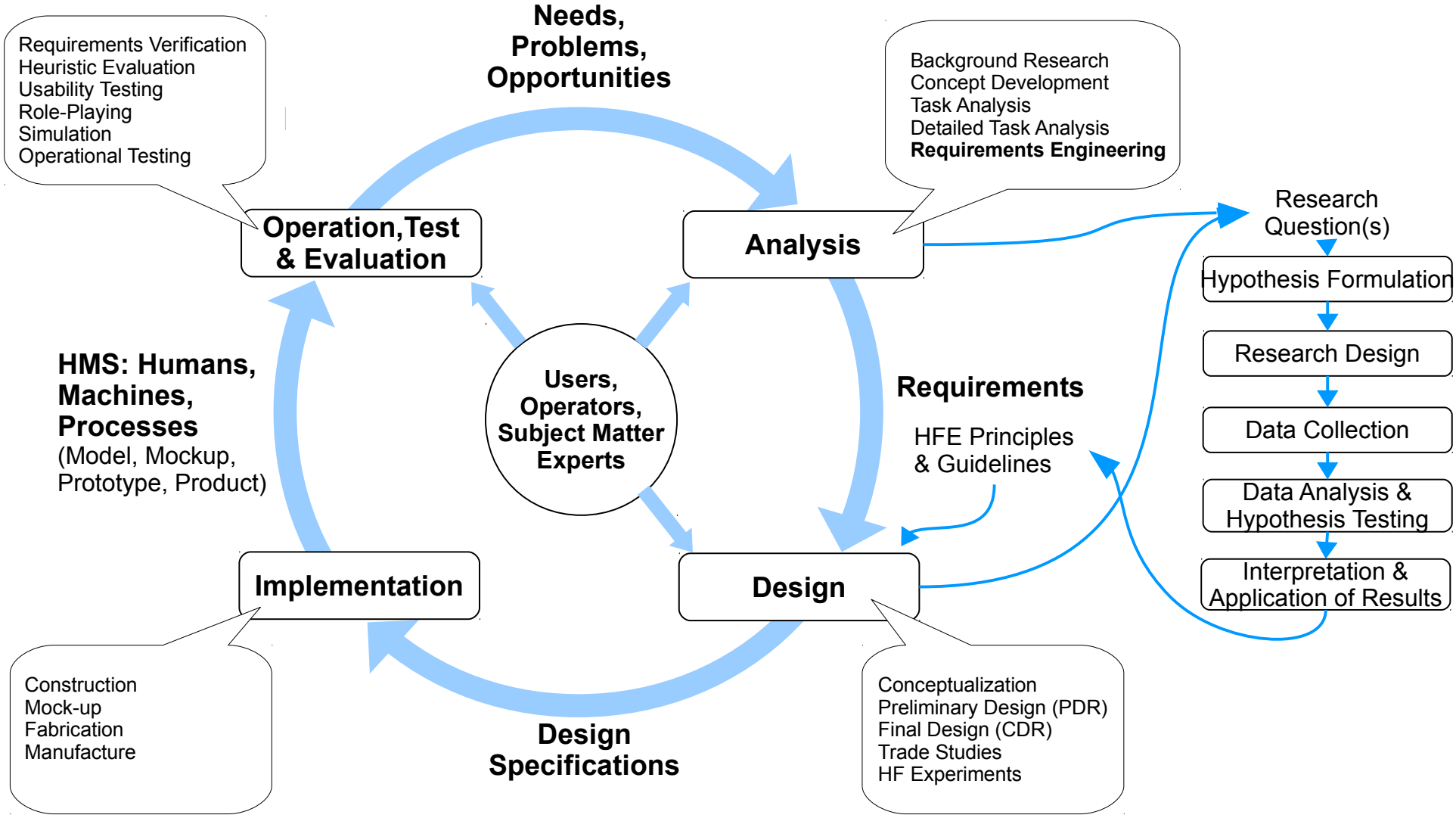

Example of the HMSE Process

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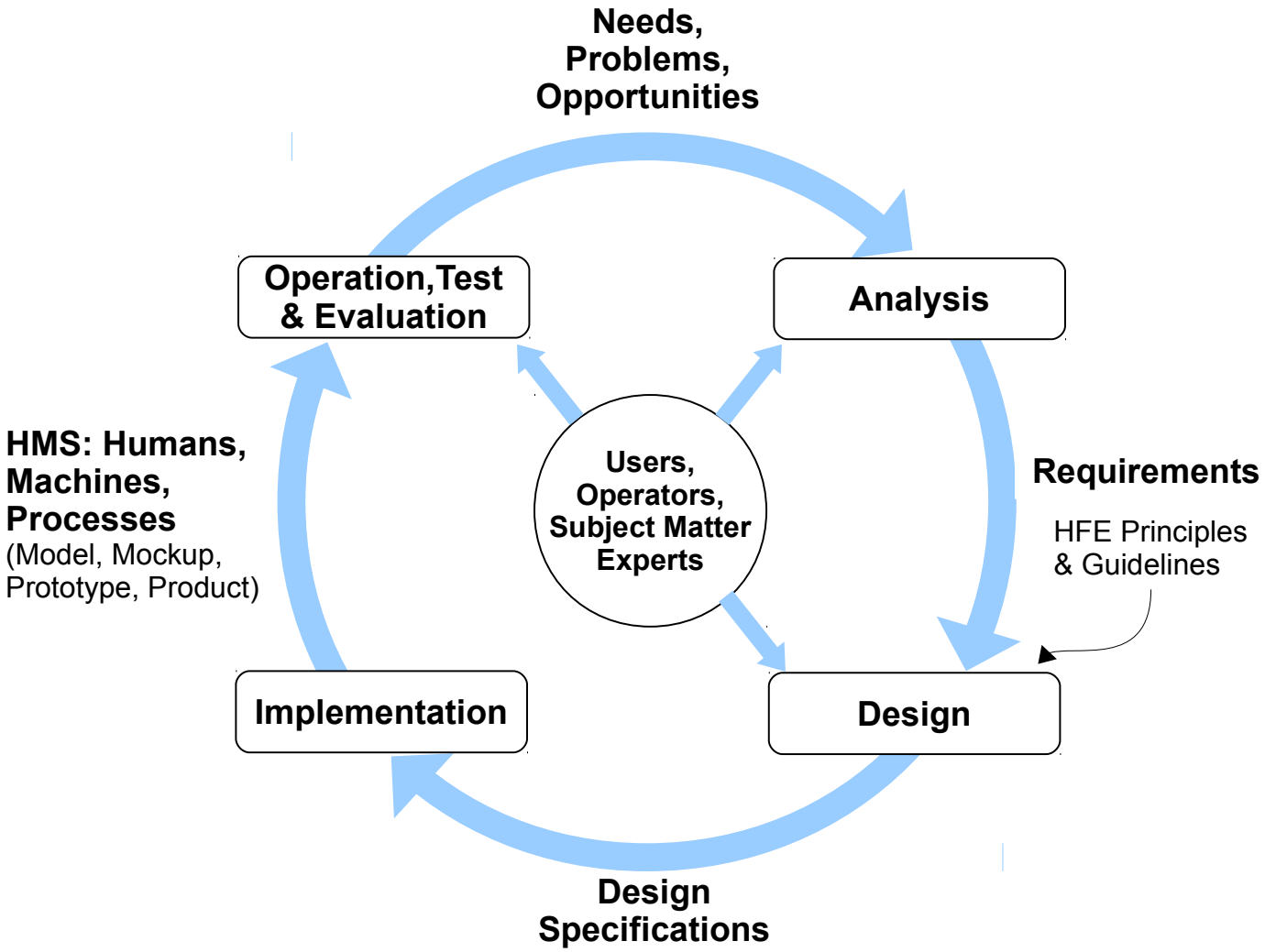
Development of the
Emergency Cesarean Delivery Facilitator
(ECDF)

A User-Centered Human-Machine Systems Engineering Process



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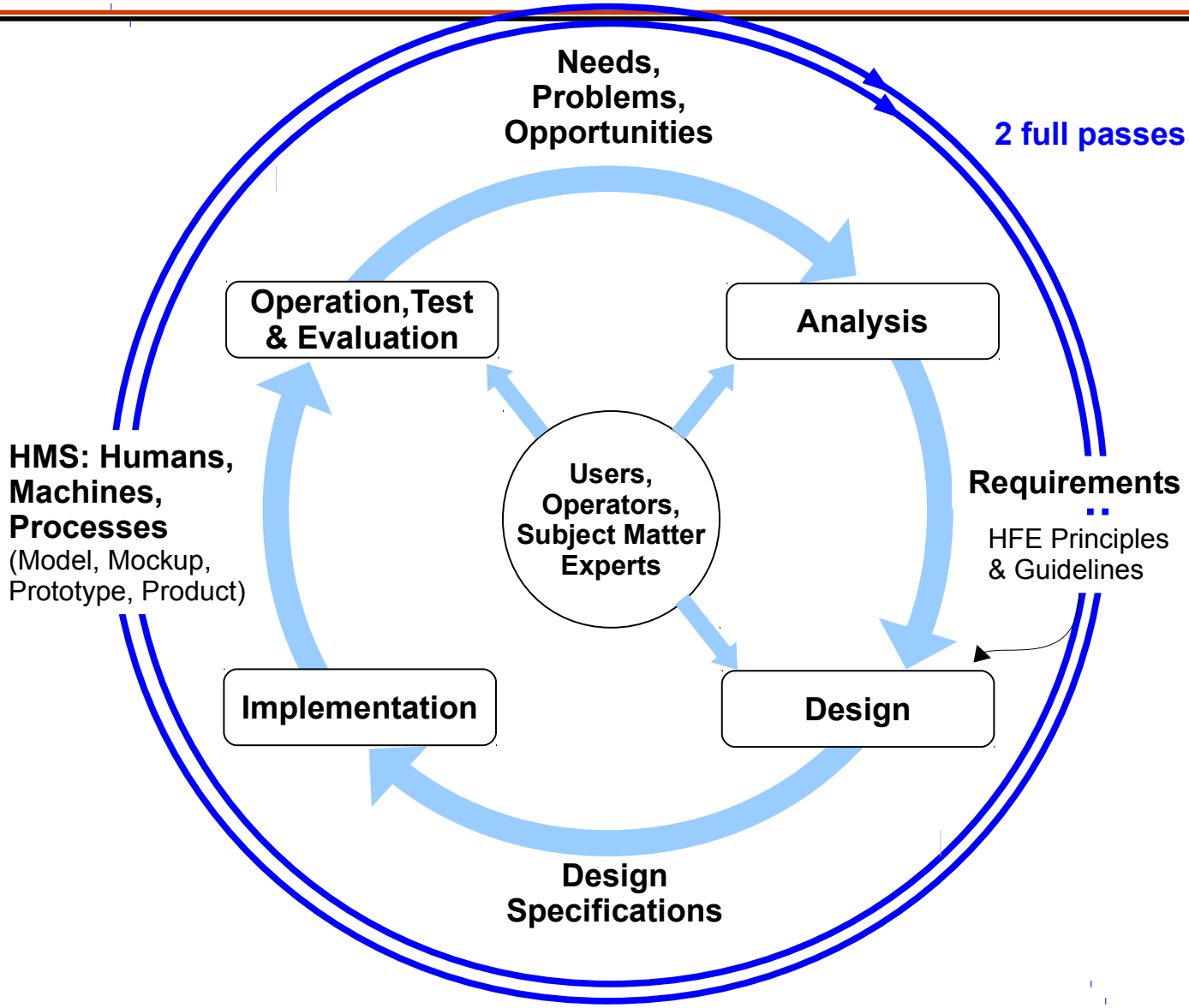

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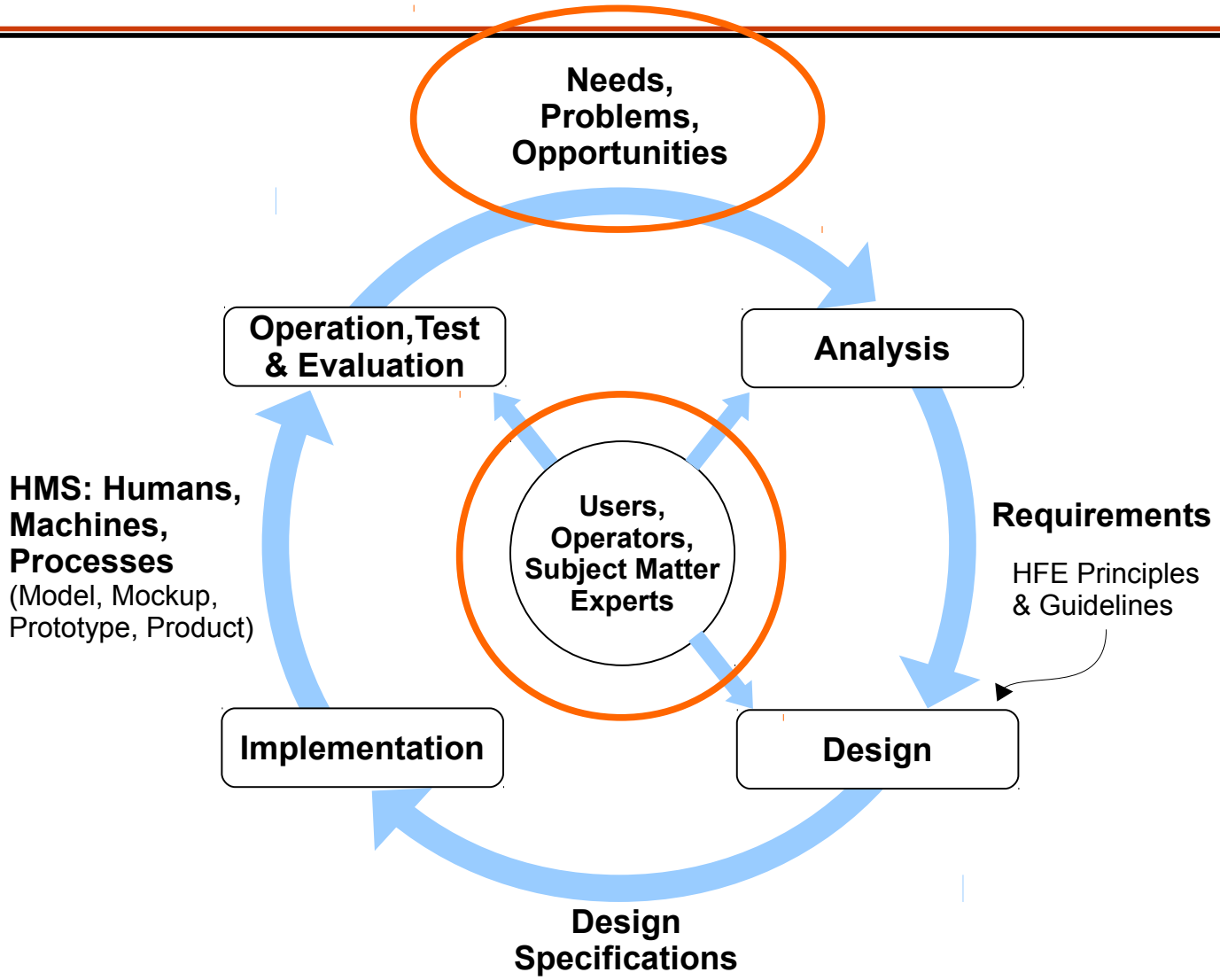
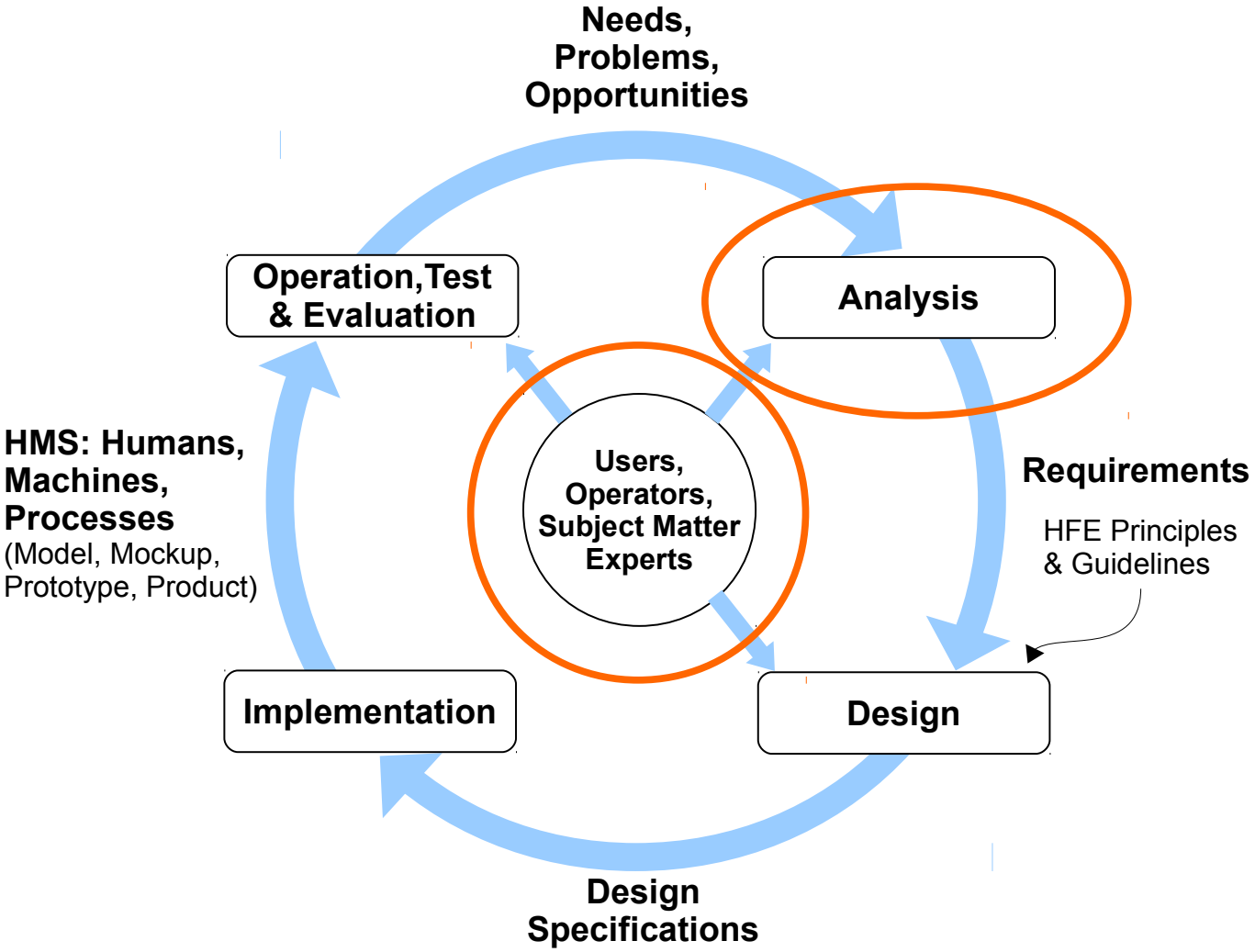


Background, Statement of Need

- Background
  - Cesarean Delivery (sometimes called Cesarean Section): surgical delivery of baby
  - System vulnerabilities, especially in small, rural hospitals
    - Inherent risk of procedure
    - Difficulty in assembling on-call team for unscheduled, emergency procedure
    - Urgent, chaotic conditions
  - Human Fallibilities (sensory, cognitive, motor)
  - System vulnerabilities + human fallibilities = delays, errors, potential for catastrophe
- Need
  - Reduce
    - “decision-incision” time
    - errors
  - Improve
    - Team communication
    - Team awareness of system, processes
    - Coordination of people, processes, procedures
- ECDF: Information & communication system to facilitate
  - Notification, assembly, preparation of team
  - Preparation of mother (and baby)
  - Preparation of operating room

A User-Centered Human-Machine Systems Engineering Process



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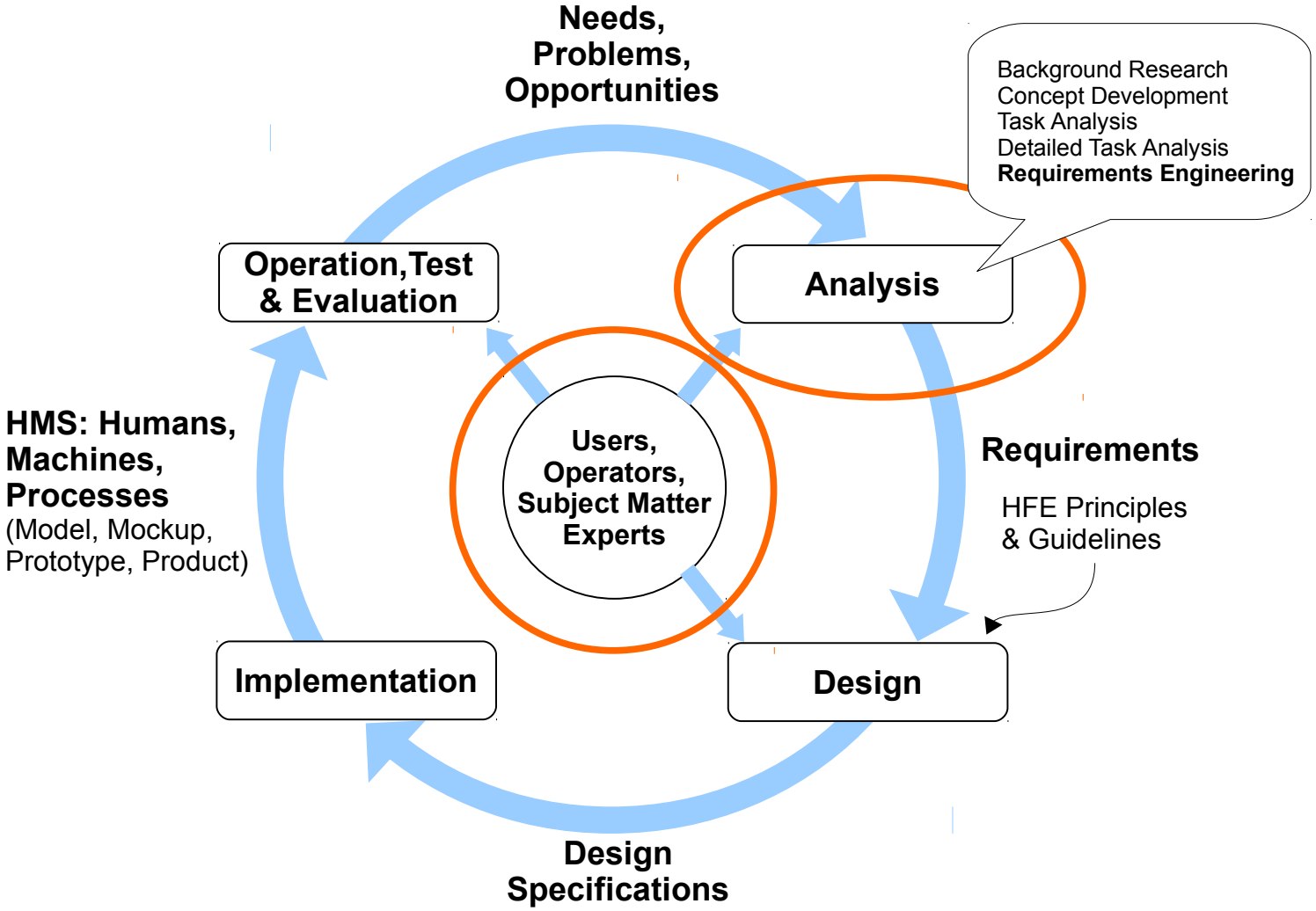
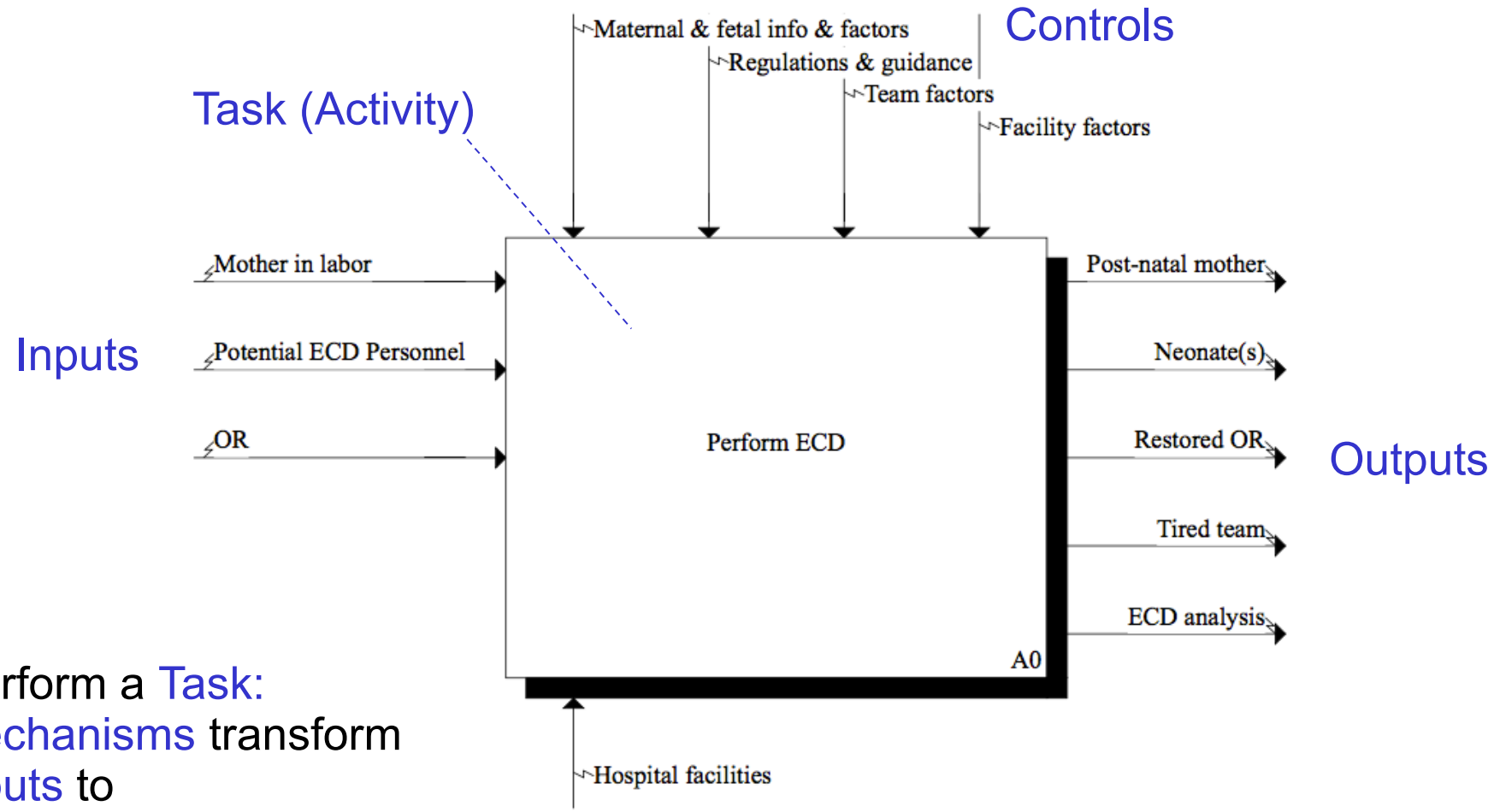


Hierarchical Task Analysis (partial): Perform Emergency Cesarean Delivery

- A0: Perform ECD
  - A1: Decide, plan, & manage delivery
  - A2: Proceed with natural delivery & recovery
  - A3: Prepare for ECD
    - A31: Summon & prepare team
    - A32: Prepare mother & fetus(es)
    - A33: Prepare OR
  - A4: Perform ECD surgery
  - A5: Restore & recover from ECD
  - A6: Analyze ECD

IDEF0 Task Analysis

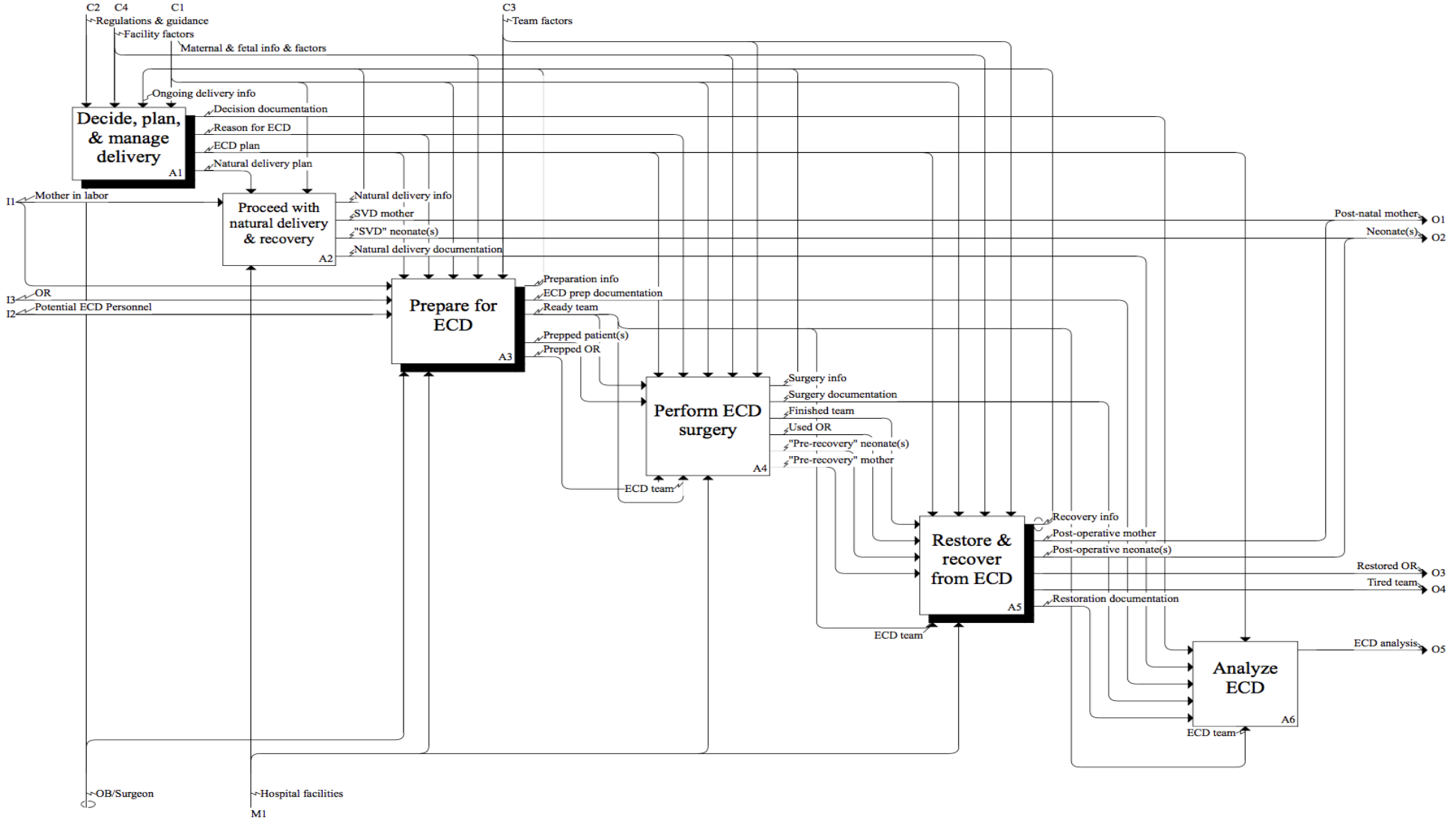
Perform Emergency Cesarean Delivery (A-0 diagram)



To perform a Task:
Mechanisms transform Inputs to Outputs, subject to Controls.

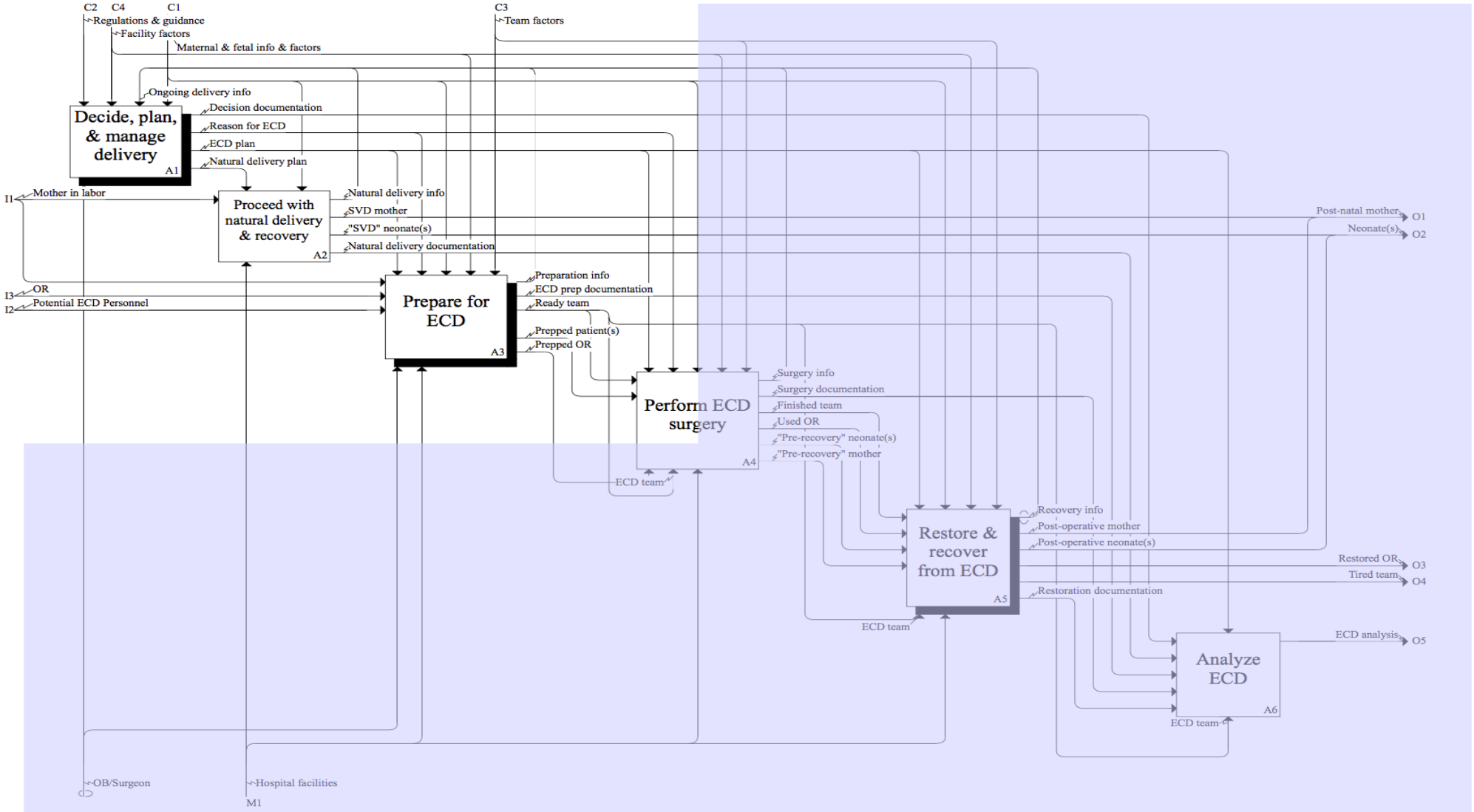
IDEF0 Task Analysis

Perform ECD (A0)



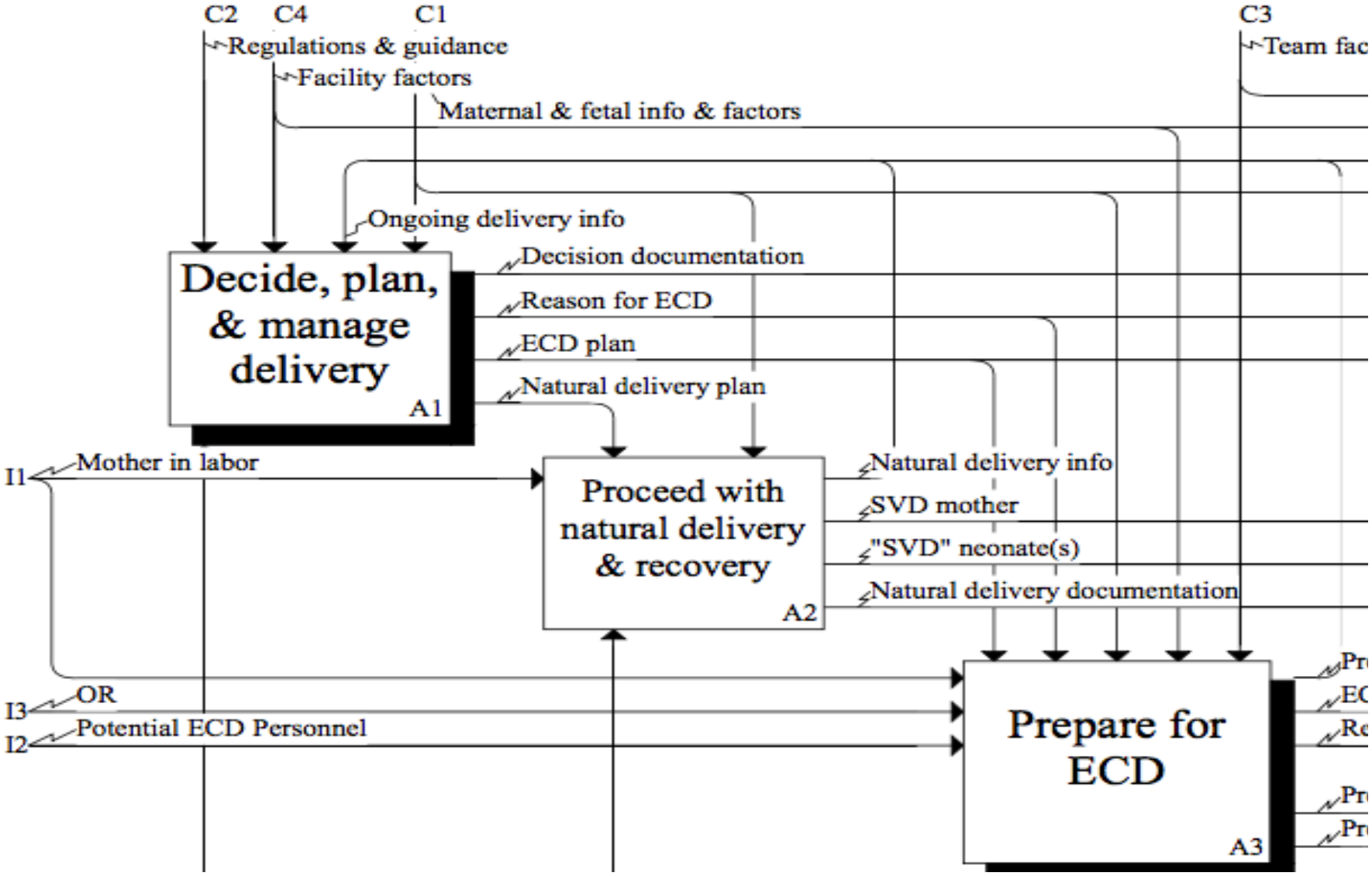
IDEF0 Task Analysis

Perform ECD (A0)



IDEF0 Task Analysis

Perform ECD (A0) Detail



IDEF0 Task Analysis

Prepare for ECD (A3)

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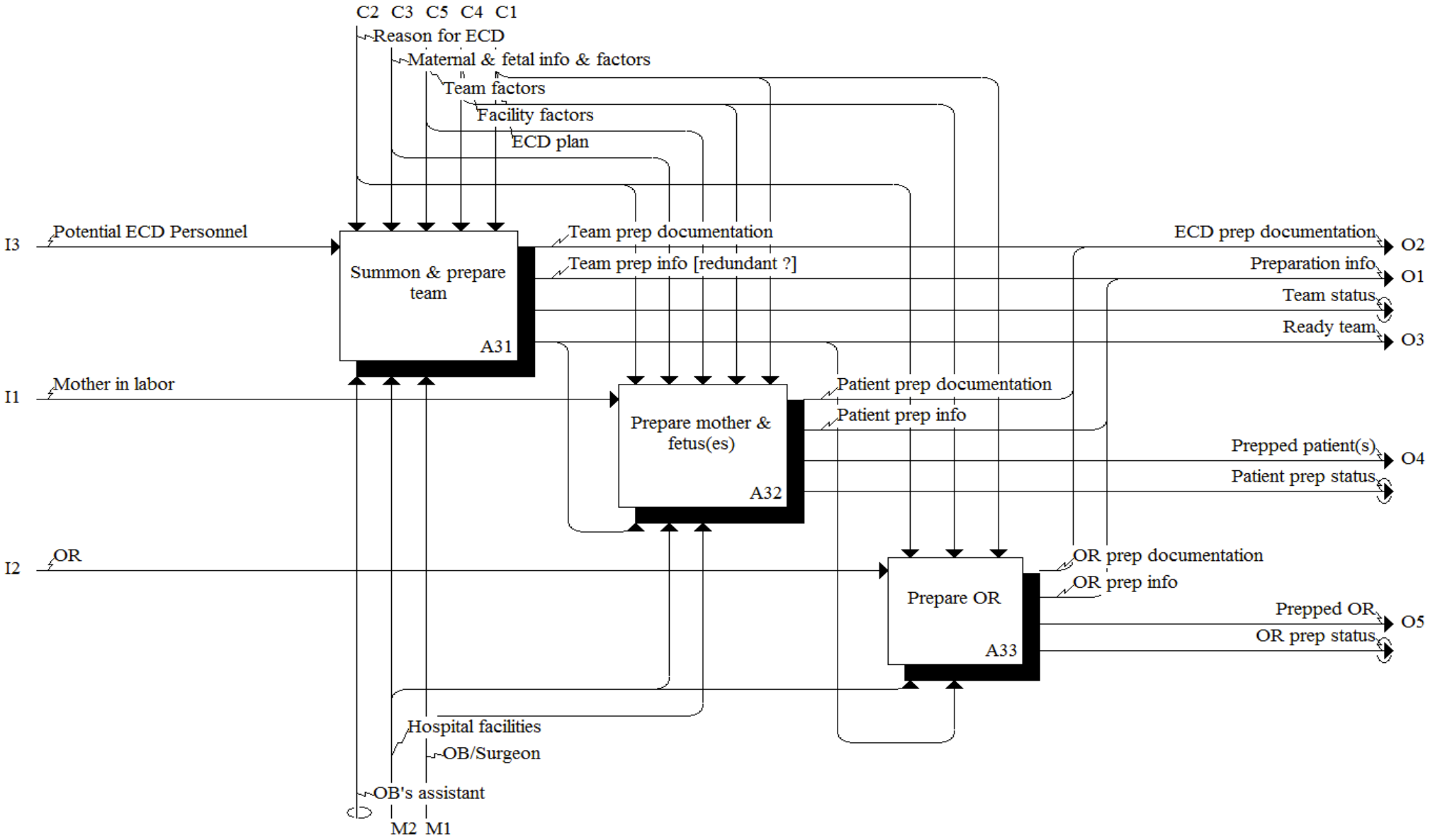

IDEF0 Task Analysis

Prepare mother & fetus(es) (A32)

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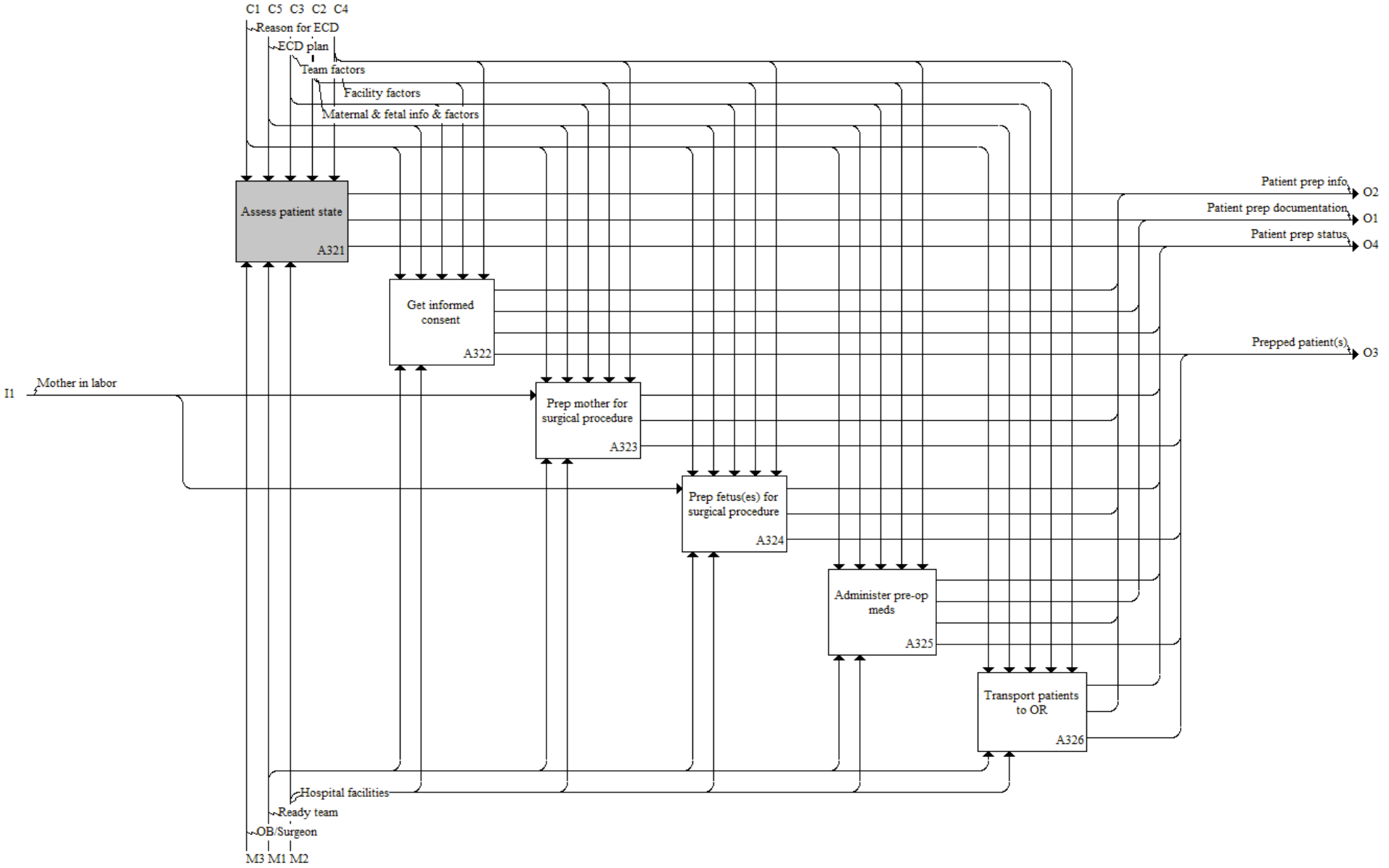
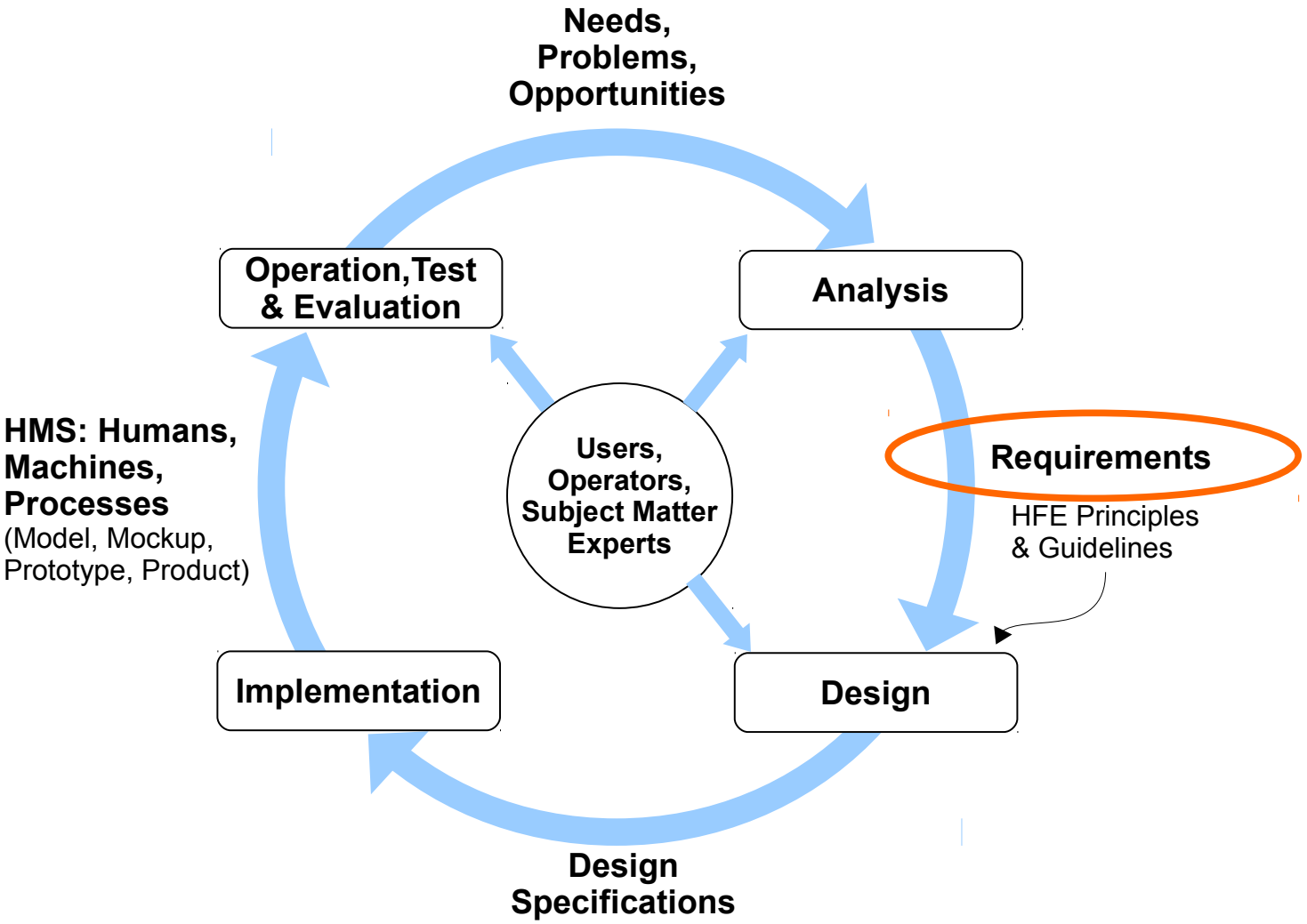


A User-Centered Human-Machine Systems Engineering Process



Some ECDF Functionality Requirements

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- The ECDF shall allow one person to simultaneously summon the entire first-call ECD Team within 3 minutes of the decision to do an ECD.
- … the ECDF shall provide guidance to Team members on how to prepare the mother and fetus(es), i.e., to:
  - assess patient state
  - get informed consent
  - prep mother for surgical procedure
  - prep fetus(es) for surgical procedure
  - administer pre-op meds
  - transport patients to OR
- ... the ECDF shall provide guidance to Team members on how to prepare the OR, i.e., the:
  - anesthesia equipment
  - surgical instruments
  - baby warmer
  - neonate resuscitation equipment
  - etc.

Some ECDF Usability/Human Factors (e.g., UI) Requirements

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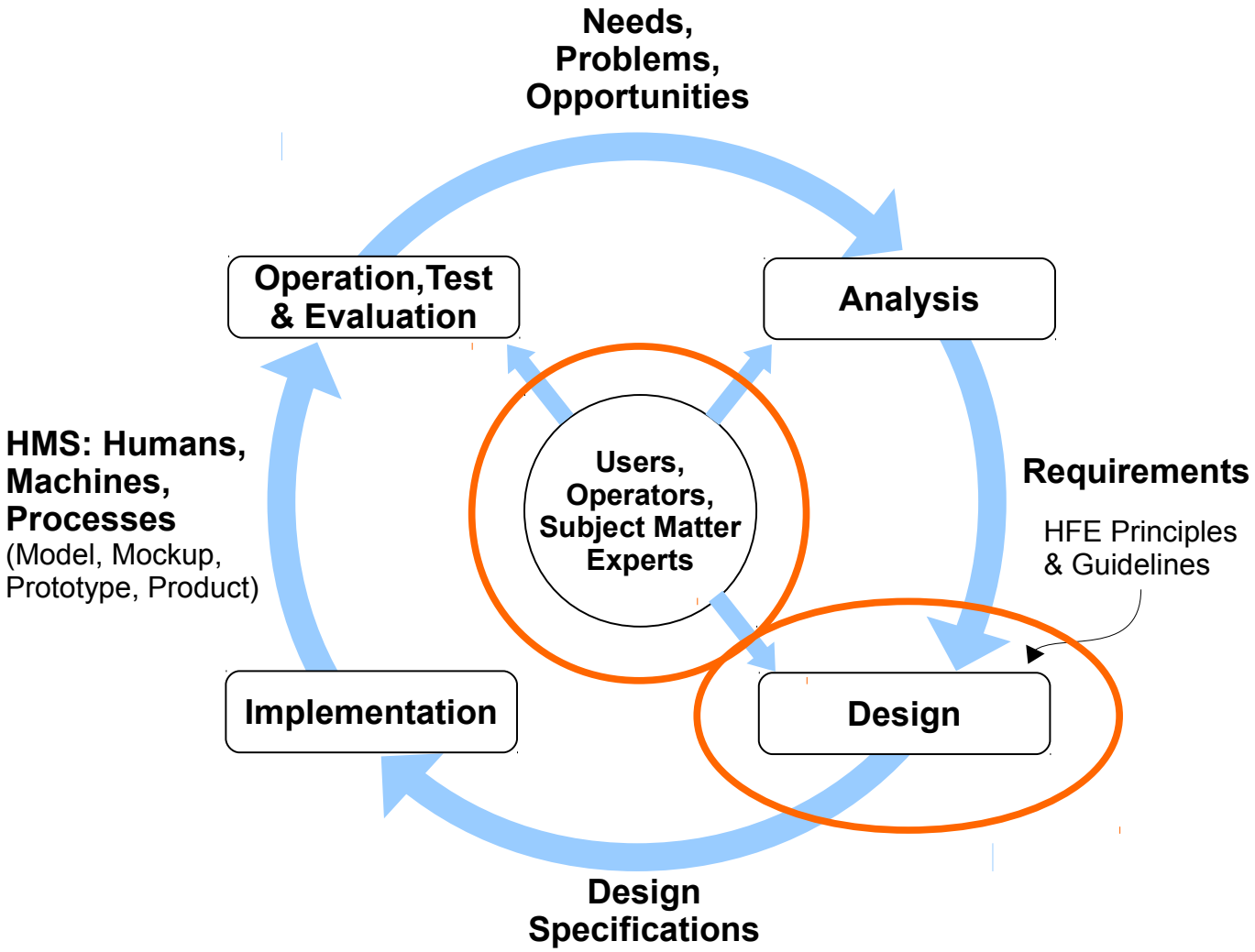
- Terminology used in the ECDF User Interface (UI) shall conform to standard medical nomenclature.
- Use of symbols, colors, and other representations shall be consistent across the ECDF UI.
- For all ECDF UI configurations in which user input is possible, either to enter data or operate the ECDF, the UI shall provide salient and meaningful visual cues as to what the user can (and, if appropriate, should) do and how to do it.
- The ECDF UI shall provide feedback for every user action detected, within 1 sec, informing the user of what function was selected or what display was requested.
- If a function or display that was requested by user action was not completed or displayed within 1 sec of the user action, the ECDF UI shall display a representation of function or display progress.

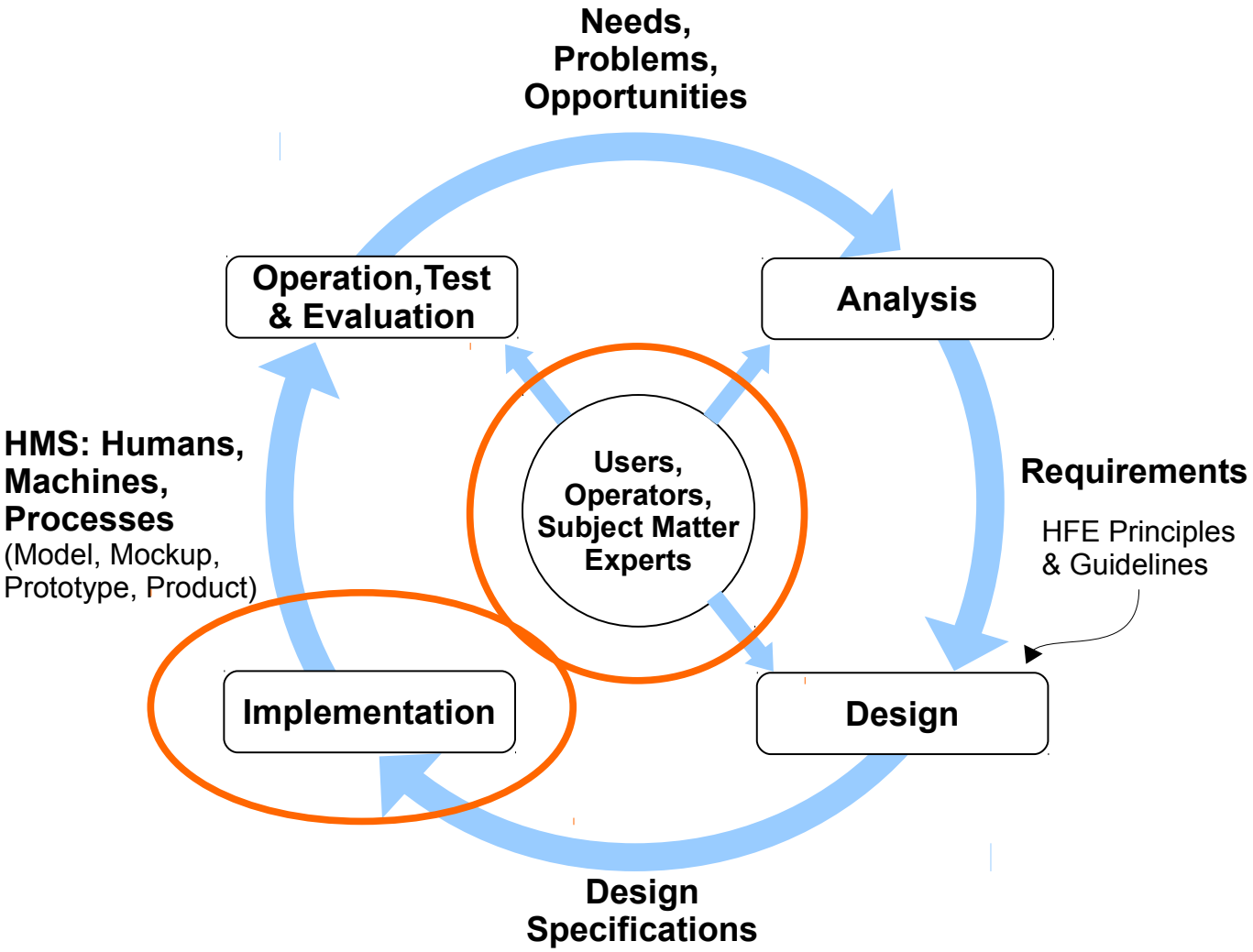
A User-Centered Human-Machine Systems Engineering Process



Design

- Process
  - Brainstorming
  - Sketching
  - Reference to requirements
  - Reference to HF principles & guidelines
  - Iteration and evaluation
- Specifications
  - Screen sketches
  - Screen descriptions
  - Narrative descriptions

A User-Centered Human-Machine Systems Engineering Process



Prototype Implementation

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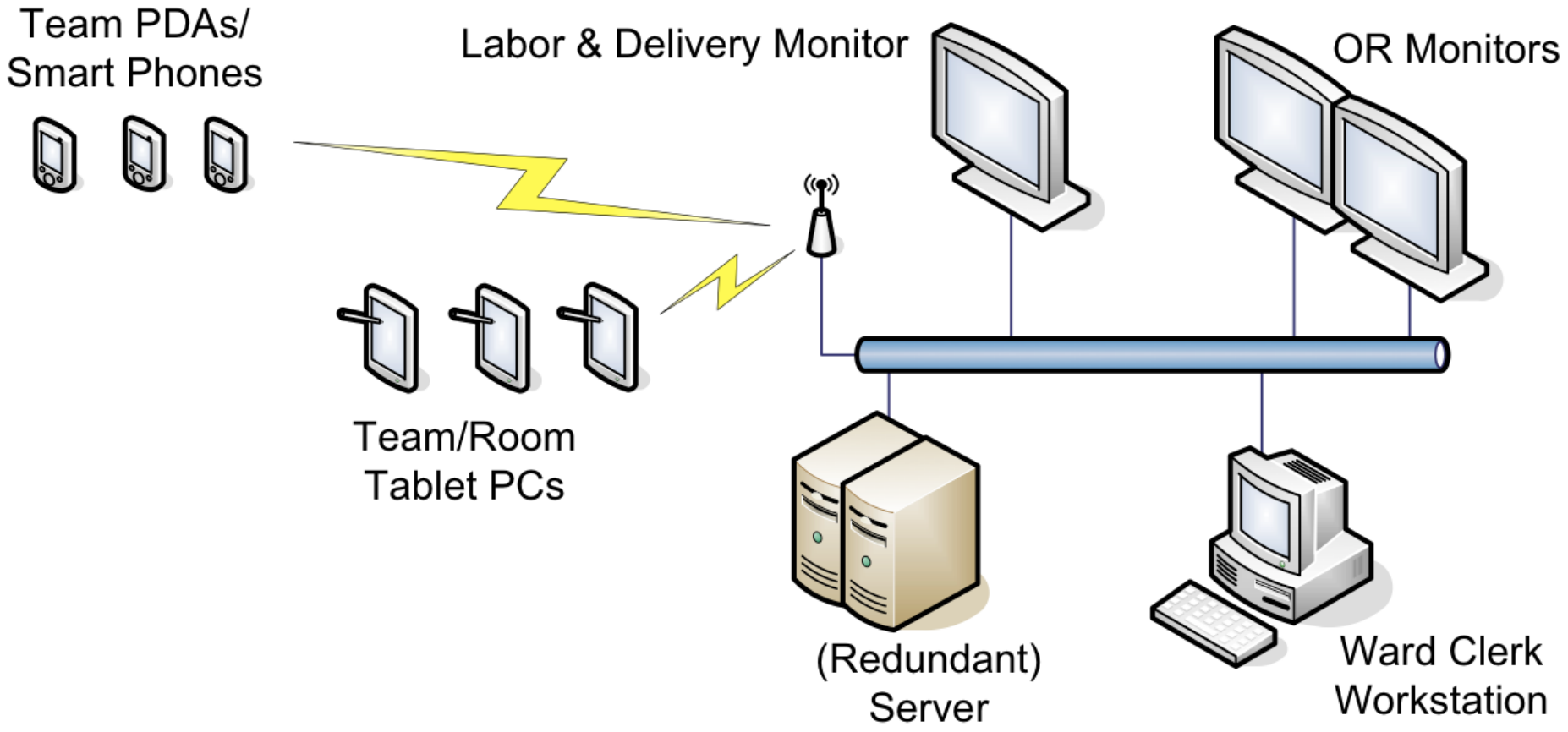
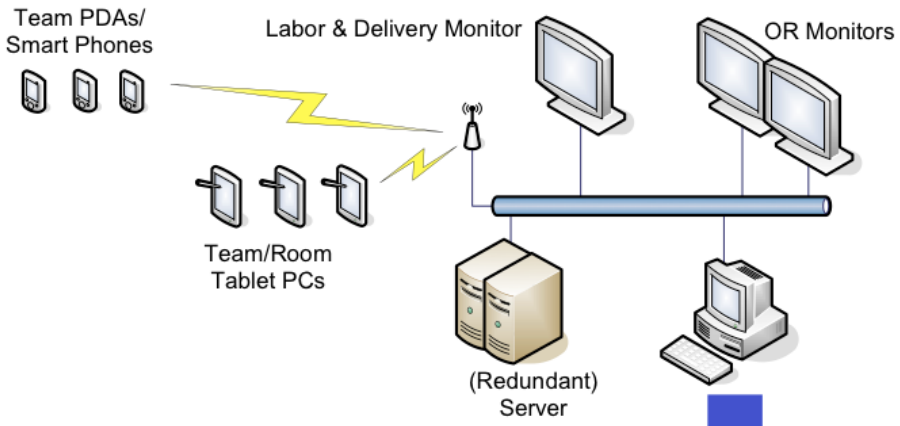
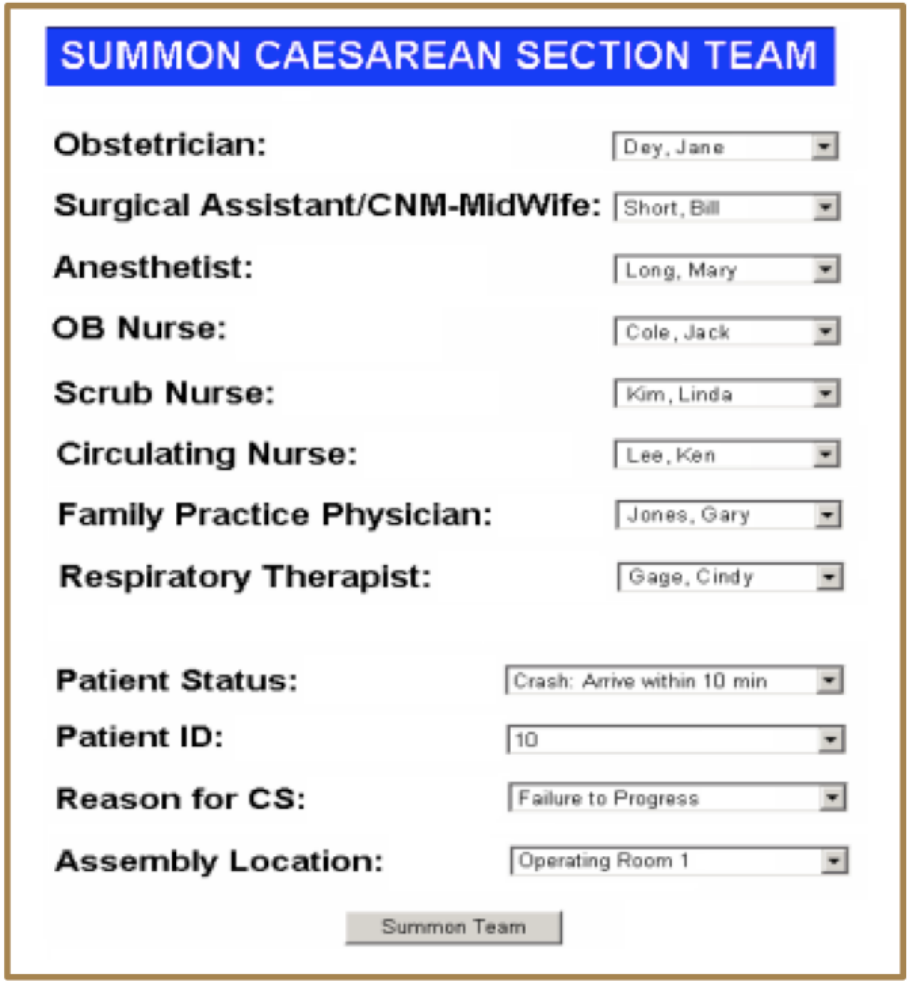
- **Prototype 1** (IE 546, Spring 2006): Electronic storyboard
  - HTML, PowerPoint
  - Screenshots from scripted scenario
- **Prototype 2** (Summer/Fall 2006)
  - Hardware: laptop server, wireless router, tablet PC, PDA
  - Software: MS Access DB, ASP.NET IDE, CSS
- **Prototype 3.0/3.1** (CS Capstone Team, 2009-10; CS major, 2013):
  - SQL database
  - HTML
- **Prototype 4** (NIH SBIR grant with Bauer Labs, 2014-15): Storyboard

ECDF Target Architecture



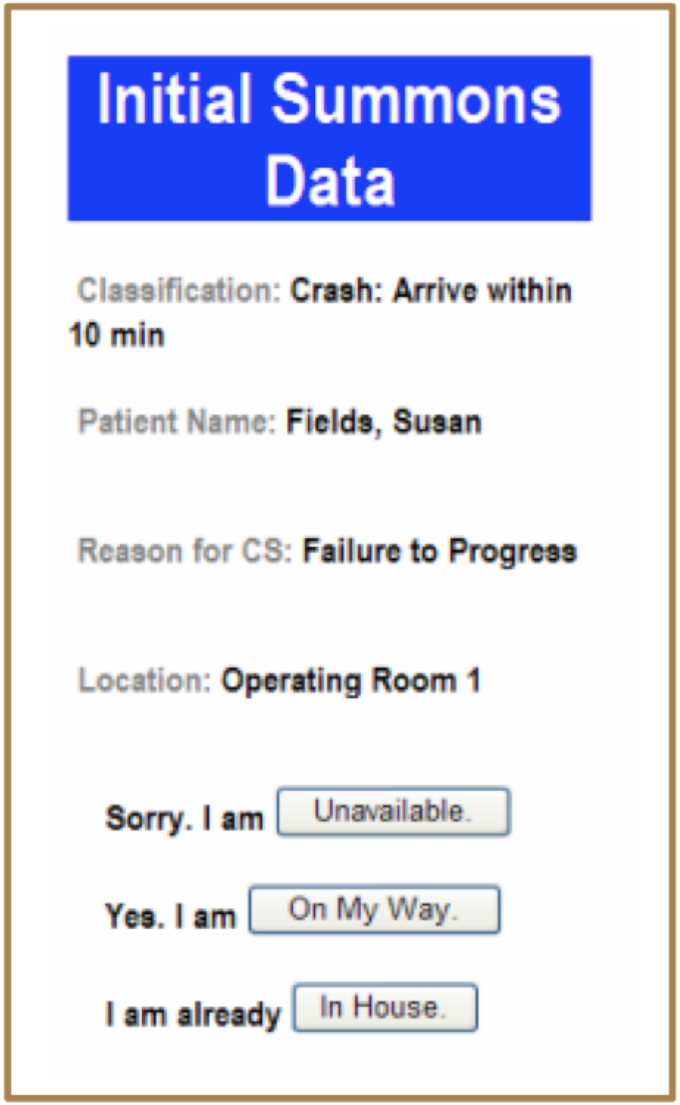
ECDF Prototype 1 Decision and Call



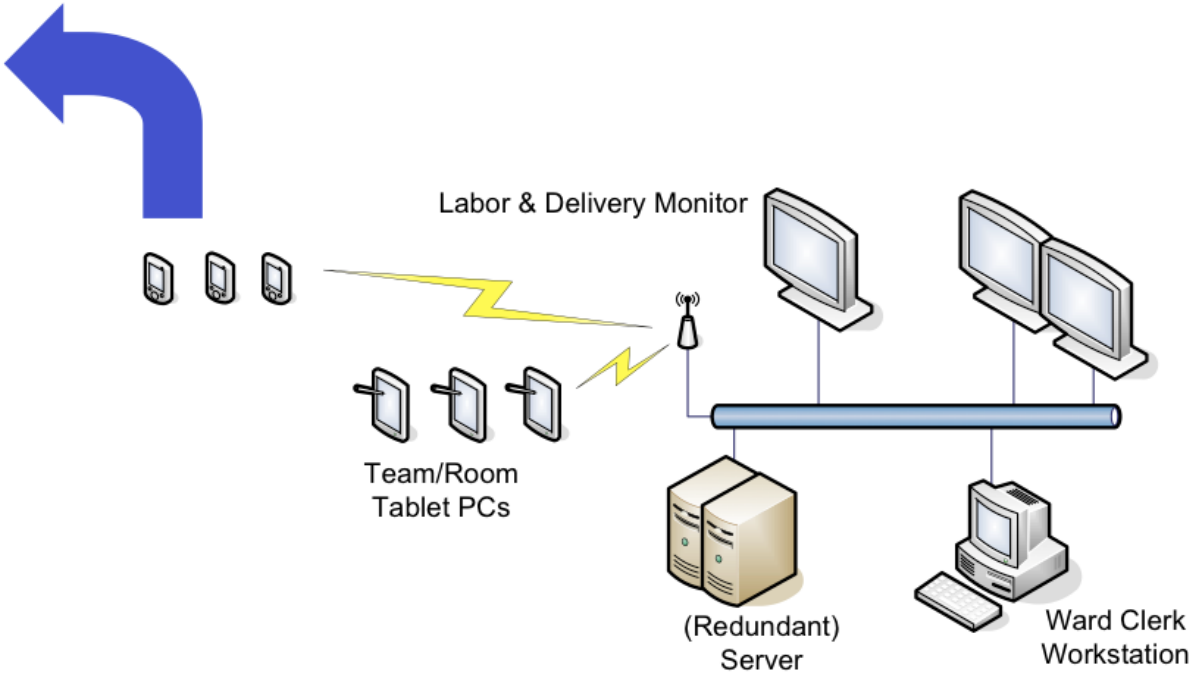


- **Delivery fails to progress.**
- **Baby at risk.**
- **Obstetrician decides to do C-Section.**
- **Ward Clerk initiates summons.**

Summons via PDAs/Smart Phones



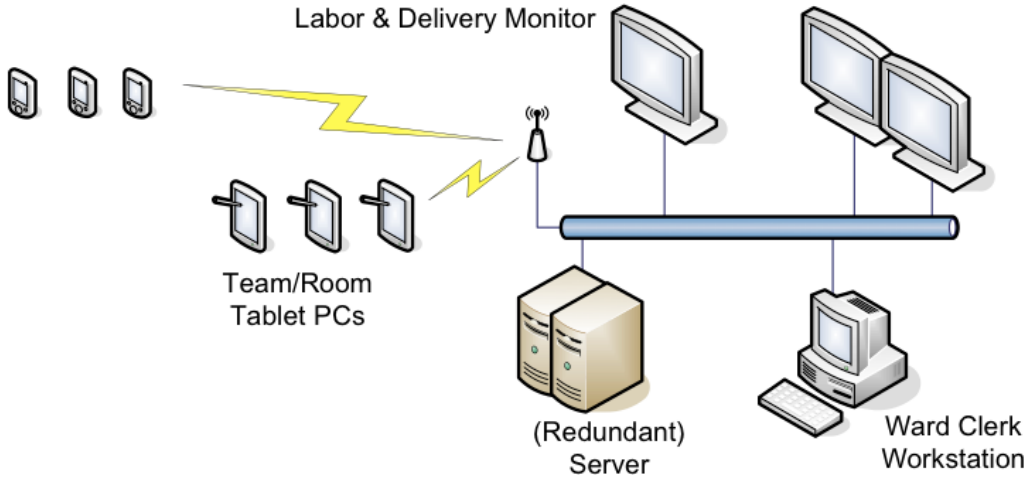
- Summons broadcast to all team members.
- Members respond.
- If unavailable, next on list summoned.



Team Status

Obstetrician Dey, Jane	✗ ▷ ✓
Surgical Assitant/CNM-Midwife Short, Bill	✗ ▶ ✓
Anesthetist Long, Mary	✗ ▷ ✓
OB Nurse Cole, Jack	✗ ▷ ✓
Scrub Nurse Kim, Linda	✗ ▷ ✓
Circulating Nurse Lee, Ken	✗ ▷ ✓
Family Practice Physician Jones, Gary	✗ ▷ ✓
Respiratory Therapist Gage, Cindy	✗ ▶ ✓

- **Available on all platforms to all team members.**



Patient Preparation With Tablet PCs Or PDAS

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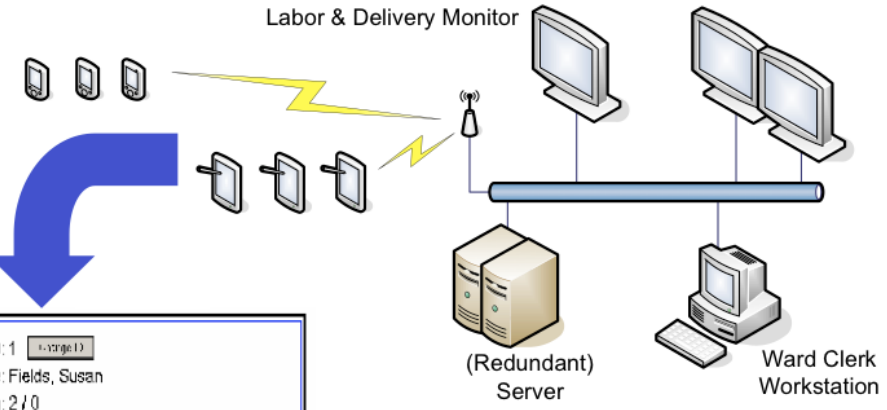
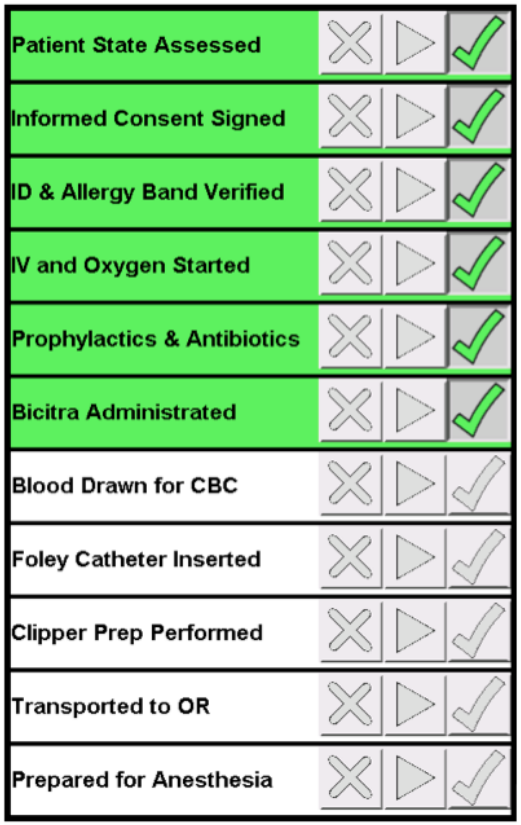
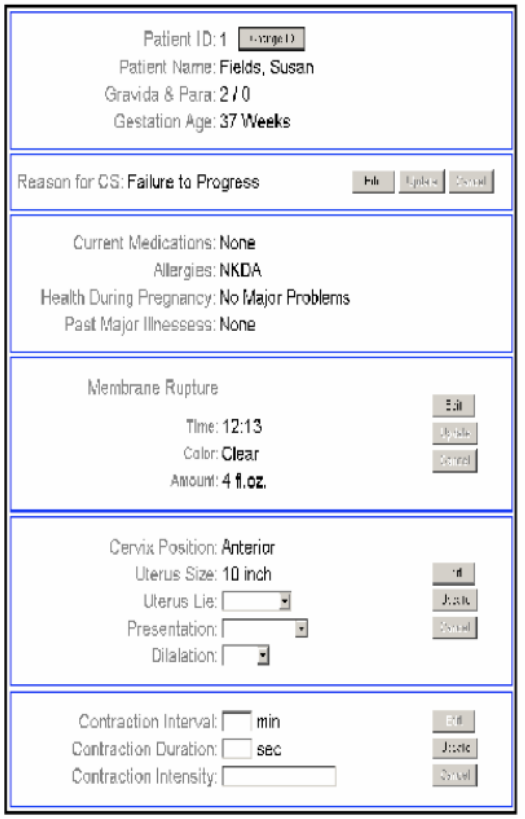
- **Nurses prepare patient (checklist).**
- **Enter patient data (entry form).**

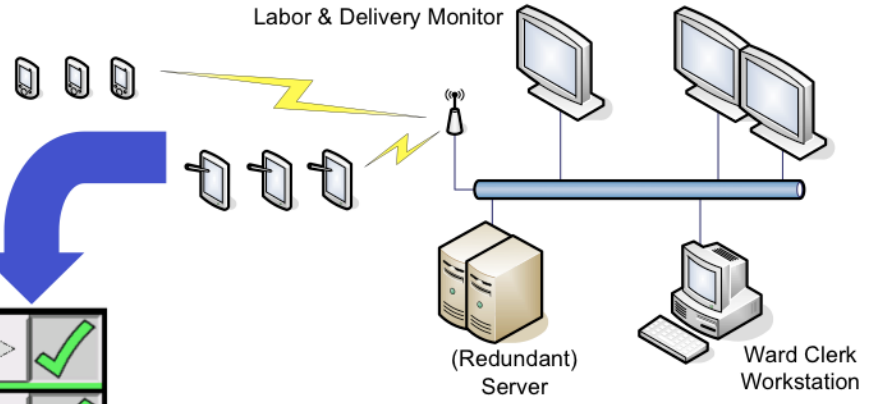






OR Preparation

- Nurses & physicians prepare OR (checklist).
- Check (√) completed items.
- Mark (►) items in progress.
- Mark (X) problem items.



Labor & Delivery, OR Status Displays

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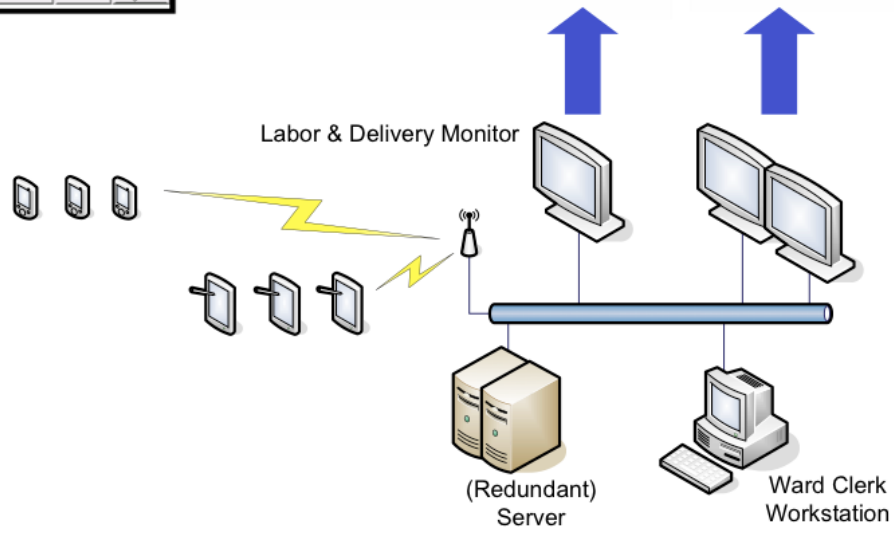
Patient State Assessed	✓
Informed Consent Signed	✓
ID & Allergy Band Verified	✓
IV and Oxygen Started	✓
Prophylactics & Antibiotics	✓
Bicitra Administrated	✓
Blood Drawn for CBC	✓
Foley Catheter Inserted	▶
Clipper Prep Performed	
Transported to OR	
Prepared for Anesthesia	

Patient ID:	10
Patient Name:	Field, Susan
Gravida & Para:	2 / 0
Gestation Age:	37 Weeks
Reason for CS:	Failure to Progress
Current Medications:	None
Allergies:	NKDA
Health During Pregnancy:	No Major Problems
Past Major Illnessess:	None
Membrane Rupture Time / Color / Amount:	12:13 / Clear / 4 fl.oz.
Cervix Position:	Anterior
Uterus Size:	3 inch
Uterus Lie:	Longitudinal
Presentation:	Breech (Butt)
Dilation:	1 cm
Contraction Interval:	11 min
Contraction Duration:	11 sec
Contraction Intensity:	Medium

Obstetrician Dey, Jane	✓
Surgical Assitant/CNM-Midwife Short, Bill	▶
Anesthetist Long, Mary	✓
OB Nurse Cole, Jack	✓
Scrub Nurse Kim, Linda	✓
Circulating Nurse Lee, Ken	✓
Family Practice Physician Jones, Gary	✗
Respiratory Therapist Gage, Cindy	▶

Anesthesia Machine	✓
Anesthesia Cart	✓
Suture Supplies	✓
Prepared Baby Warmer	
Oxygen & Airway Supplies	✓
Surgical Equipment	✓
Table & Lighting	✓
Mayo Stand & Instruments	✓
Neonatal Crash Cart	✓
Suction Vacuum	✗



Status displays also available on

- **Tablets**
- **PDAs**
- **Desktops**

Prototype Implementation

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- **Prototype 3.0/3.1** (CS Capstone Team, 2009-10; CS major, 2013):
  - SQL database
  - HTML
  - Web browsers
- **Prototype 4** (NIH SBIR grant with Bauer Labs, 2014-15): Storyboard
  - Storyboard: screenshots in scenario

Prototype 3.0/3.1

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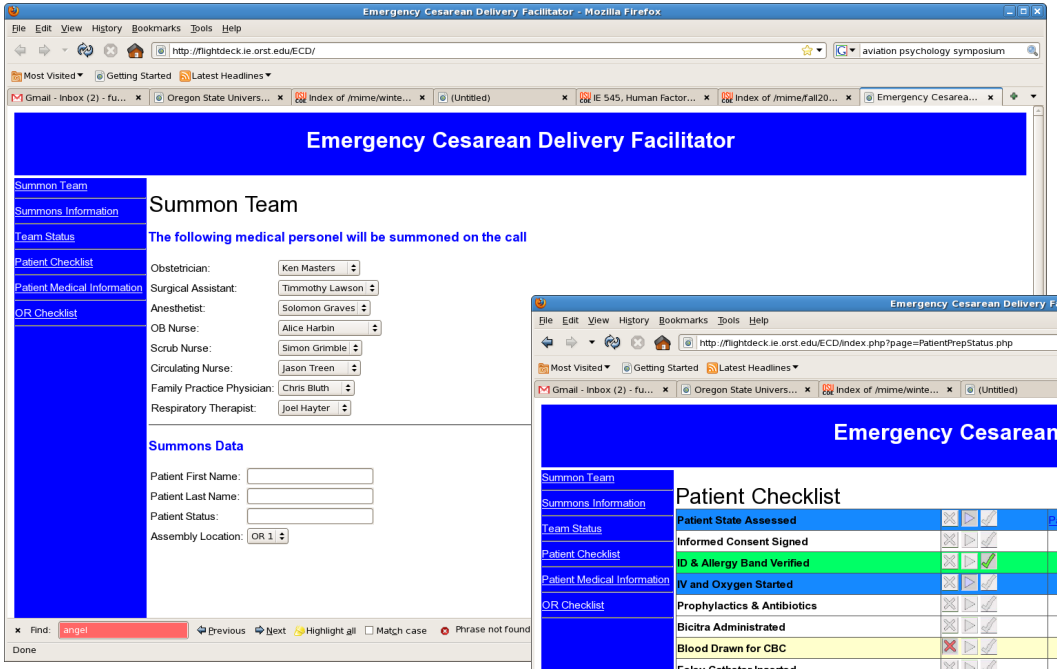
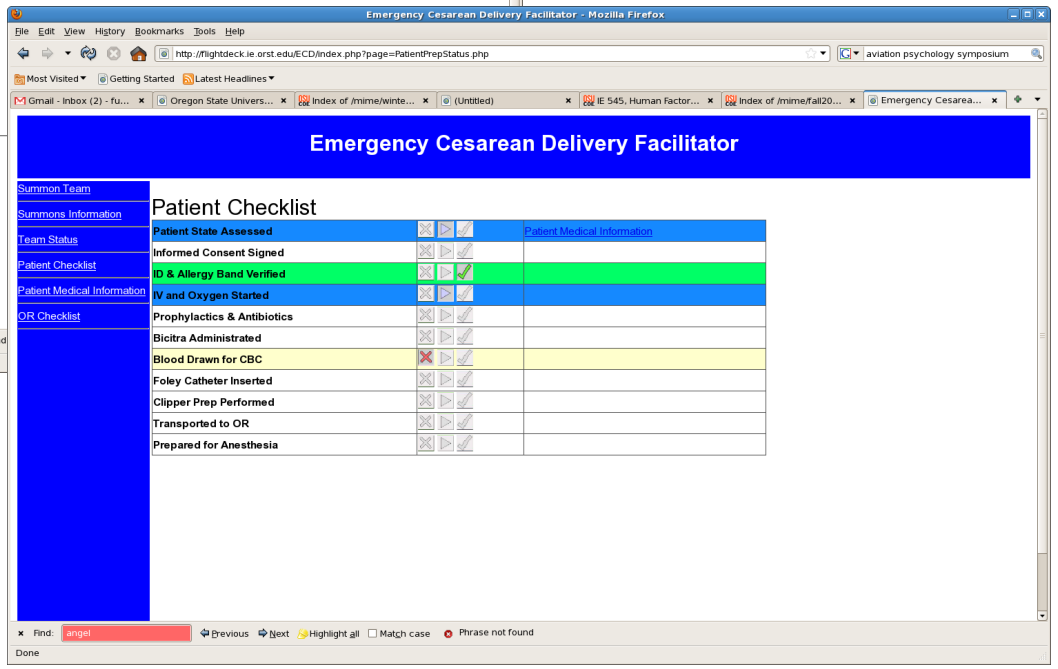
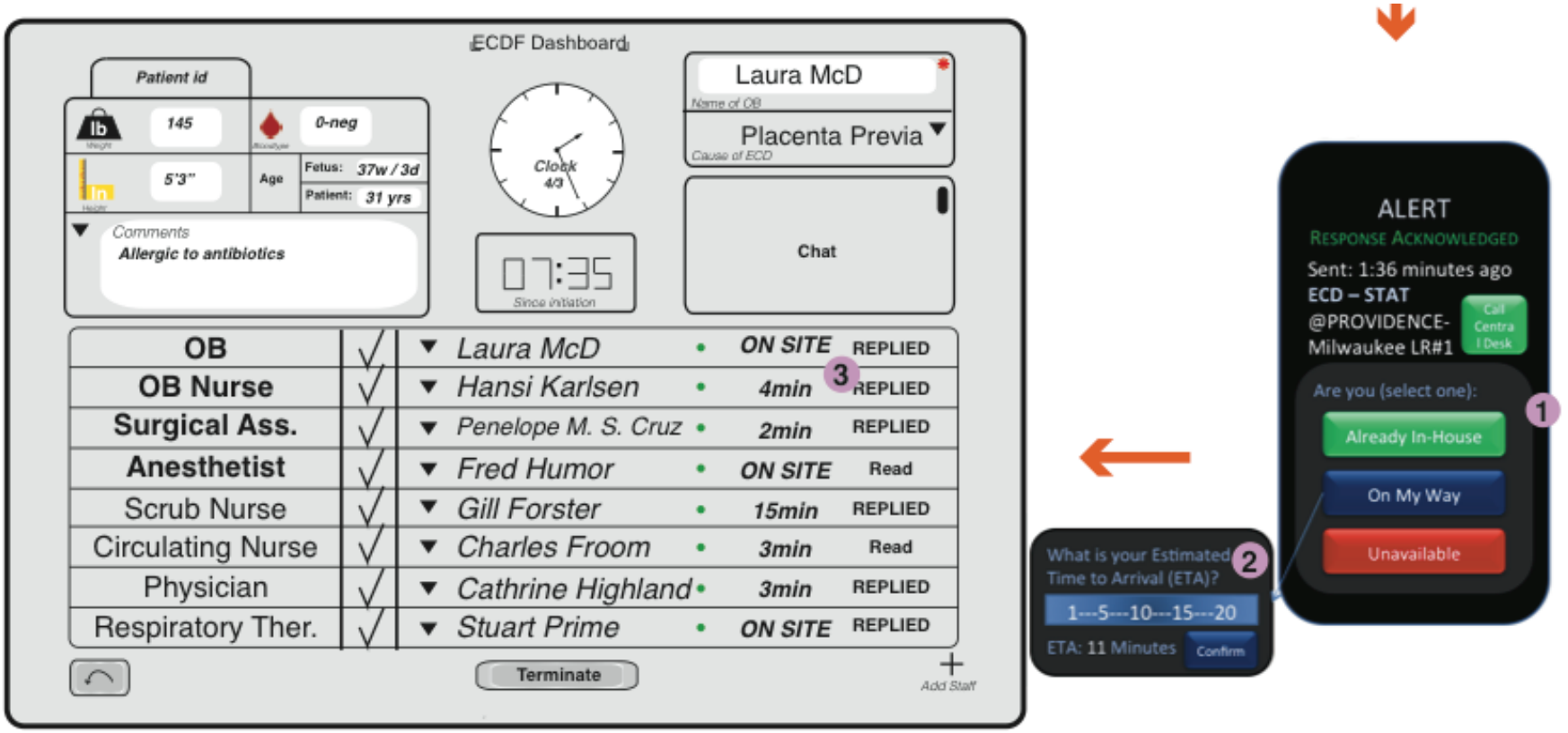




http://flightdeck.ie.orst.edu/ECD/

Prototype 4



View 15a: *Staff members reply with their avaiability and estimated time of arrival (ETA) via app.*

Main interactions :

1 *Staff members reply*
2 *Staff members notes ETA*
3 *ETA and notification status*

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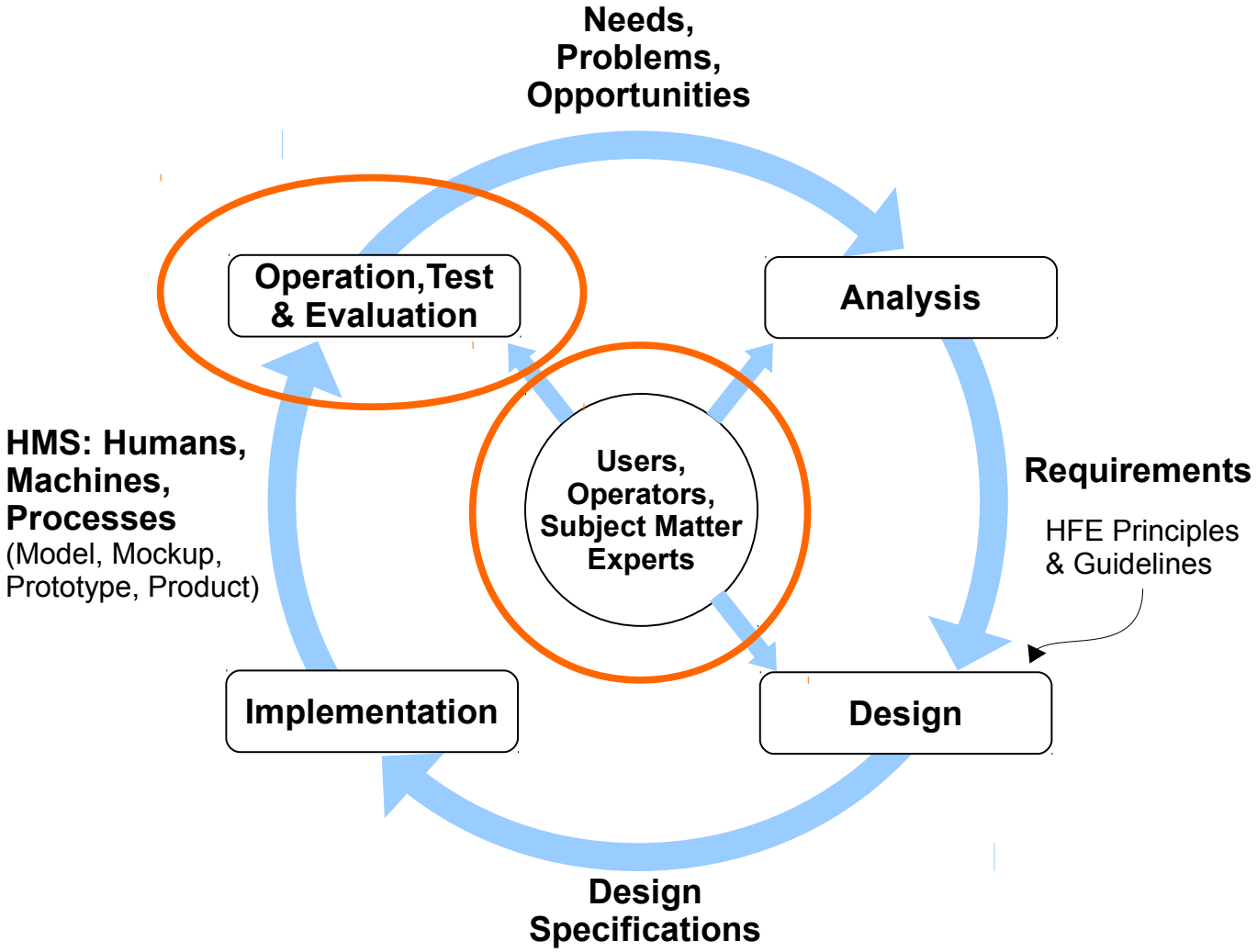

Operation and Evaluation of Prototype 2

Oregon State University College of Engineering

- Demonstration scenario at PeaceHarbor Hospital, Florence, Oregon
  - Unplanned Cesarean delivery due to failure to progress
  - Problems
    - First-call pediatrician fails to respond
    - Baby warmer prep assigned to RNA, miscommunicated
    - Problem with equipment in the OR (forceps and Kiwi).
- Usability assessment
  - Learnability
    - intuitive
  - Efficiency
    - Easy entry of patient data
    - Simple
    - Good interface design
  - User satisfaction
    - Great
    - Better communication
    - No rigid enforcement of procedural order
    - No major problems
  - Recommendations (implemented in previous screenshots)
    - Less intense colors
    - Different icons
    - Reduced display clutter

Operation and Evaluation of Prototype 3

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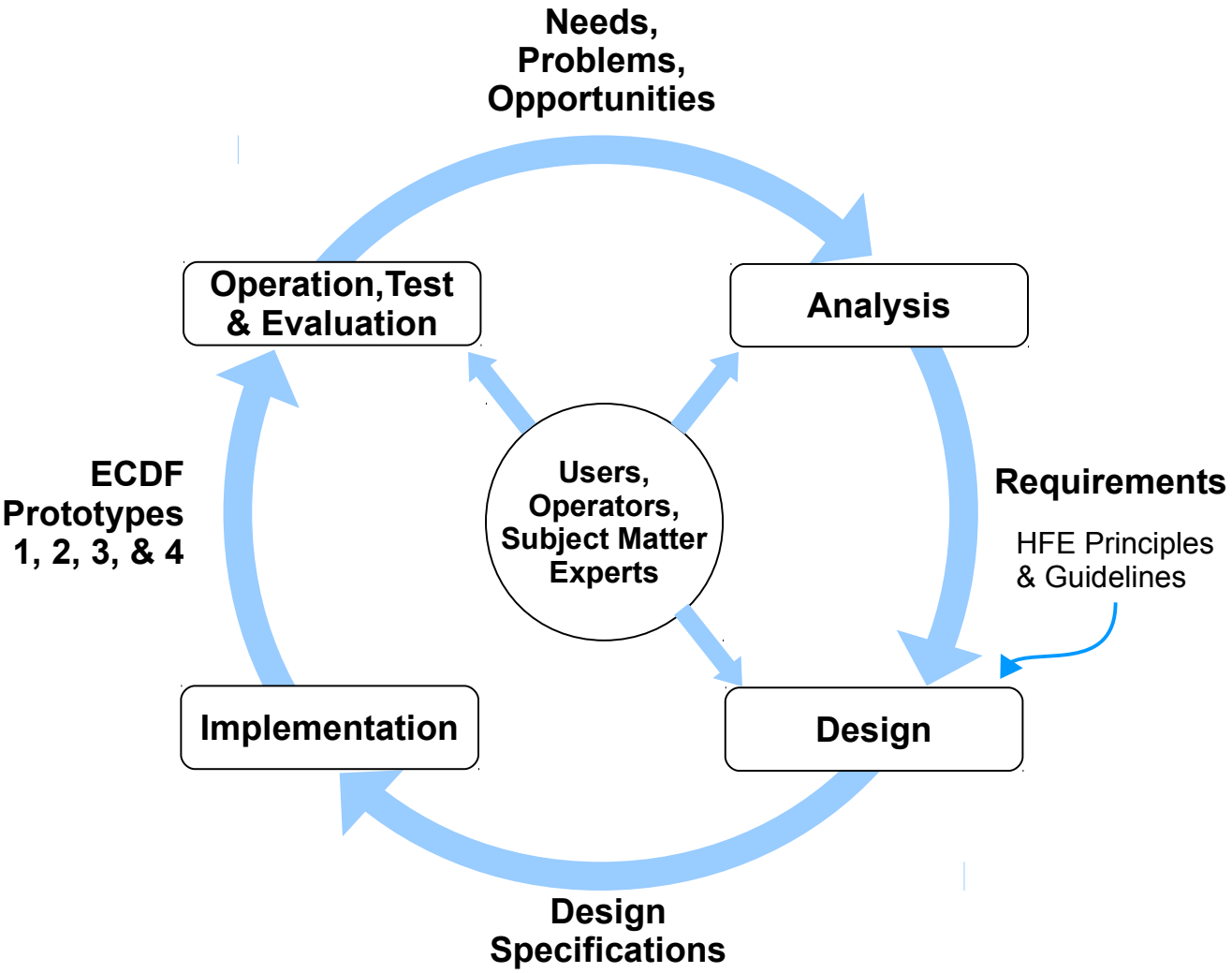
(Done as a rehearsal for a hospital trial that was not conducted.)

- Apparatus: ECDF 3.1 (web-based prototype)
- Participants: OSU students (surrogate users) playing ECD team roles
- Setting: “home” (BAT 050), “labor & delivery room” (ROG 226), and “OR” (COVL 117)
- Scenario, run by GRA
  - ECD decision
  - Summons
  - Response
  - Patient “prep” & data entry
  - OR “prep” & data entry
  - problems/challenges: declines/no responses, finding equipment & material
- Data collection
  - Event times, e.g., start of trial, ECD decision team arrivals,patient readiness, OR equipment readiness, initial incision (→ decision-to-incision time), participant observation
  - Questionnaire (?)
    - Functionality, e.g., prep reminders: rating (+/-), comments, suggestions
    - Usability, e.g., information presentation: rating (+/-), comments, suggestions
- Findings
  - Decision-Incision < 30 min.
  - Limitations in prototype, scenario, and instruments to be addressed in further development and testing

Summary, Discussion, Plans

- Requirements development through IDEF0 process modeling
  - Systematic, top-down knowledge elicitation
  - Shared vocabulary, understanding among engineers, users
- Rapid prototyping with off-the shelf components
- Prototypes: Storyboards and Part-Functional Prototypes
  - Mobile, wireless information/communication system to facilitate
    - Surgical team assembly and preparation
    - Patient preparation
    - Preparation of operating room
    - Situation awareness: patient, OR, team
  - Well-received by users
  - Believed that it would significantly reduce decision-incision time
- Future plans: No further development, but application of concepts to other domains.

A User-Centered Human-Machine Systems Engineering Process