

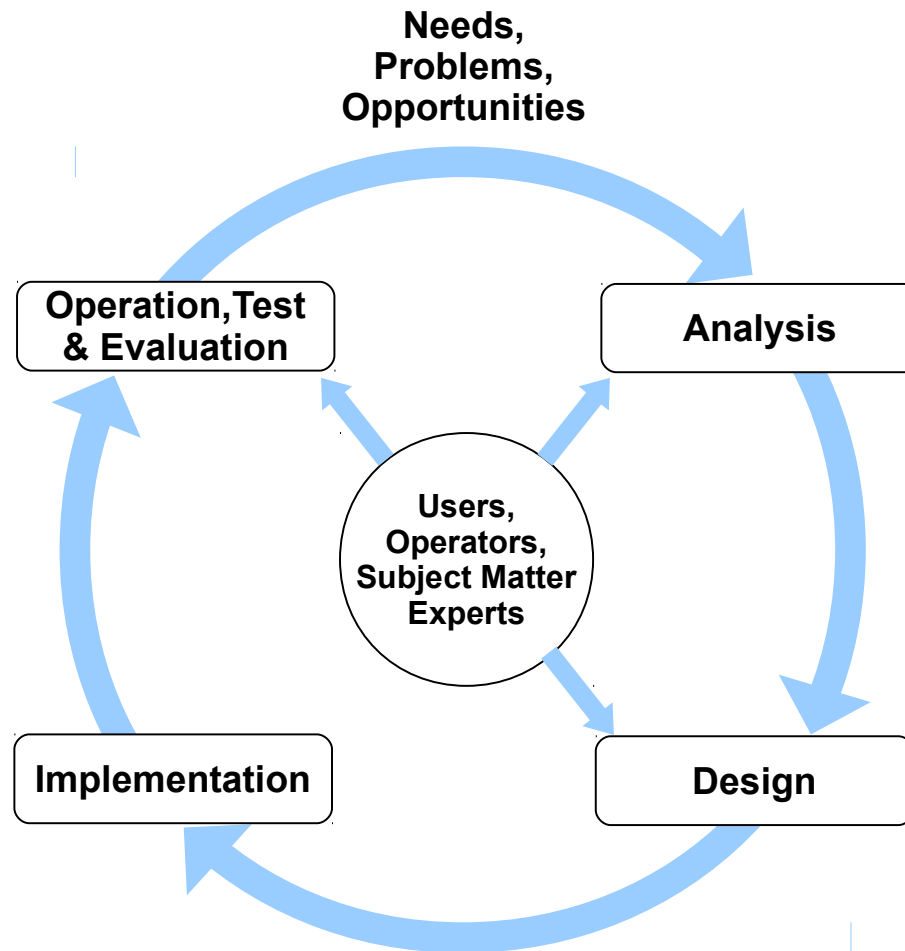
Human-Machine Systems Engineering

Introduction & Example

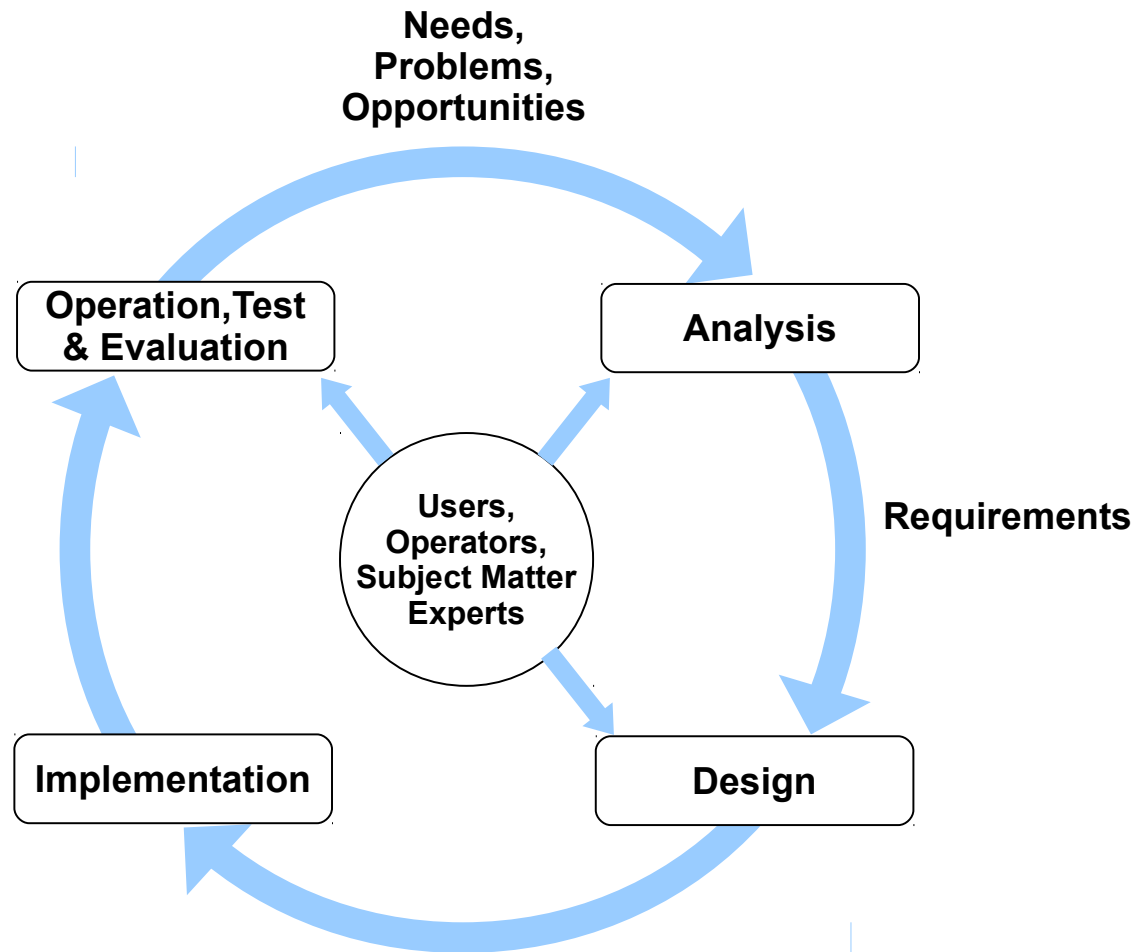
A User-Centered Human-Machine Systems Engineering Process

**Needs,
Problems,
Opportunities**

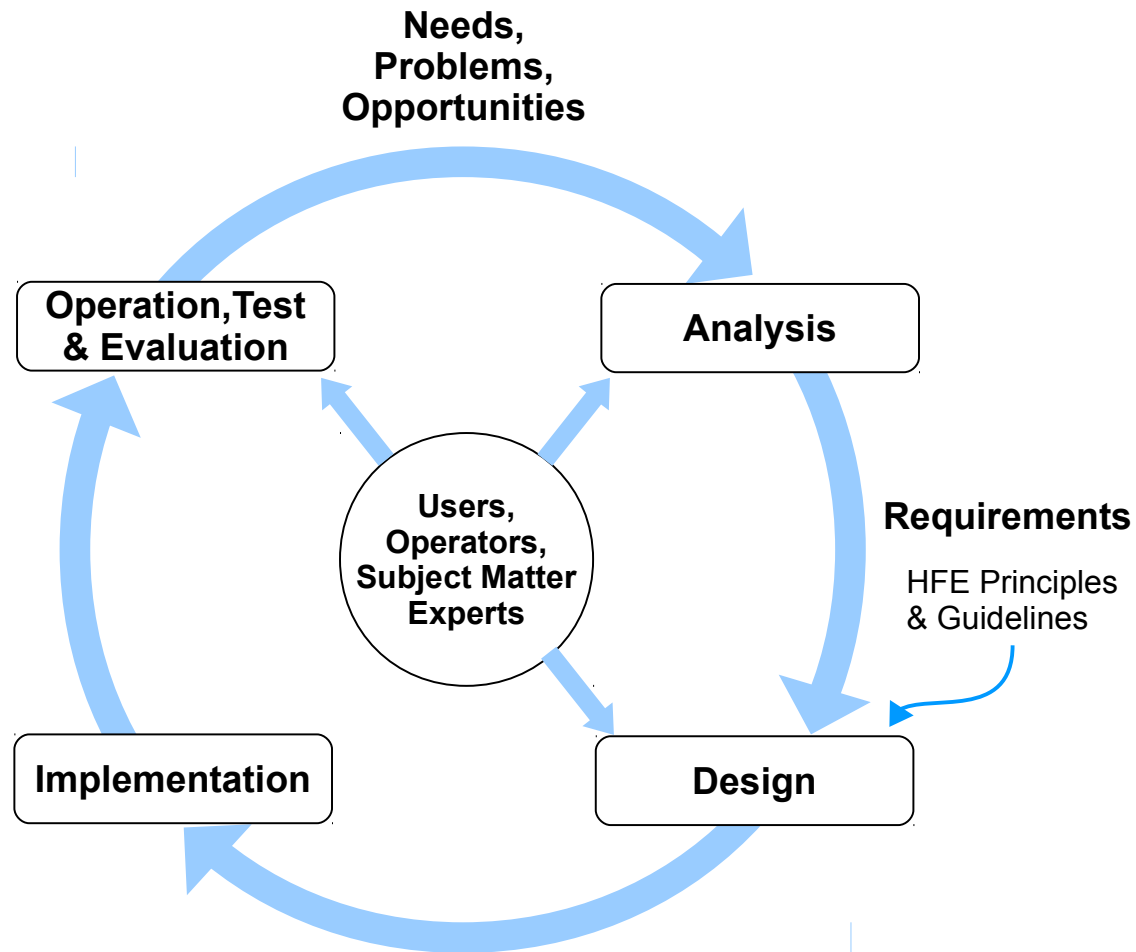
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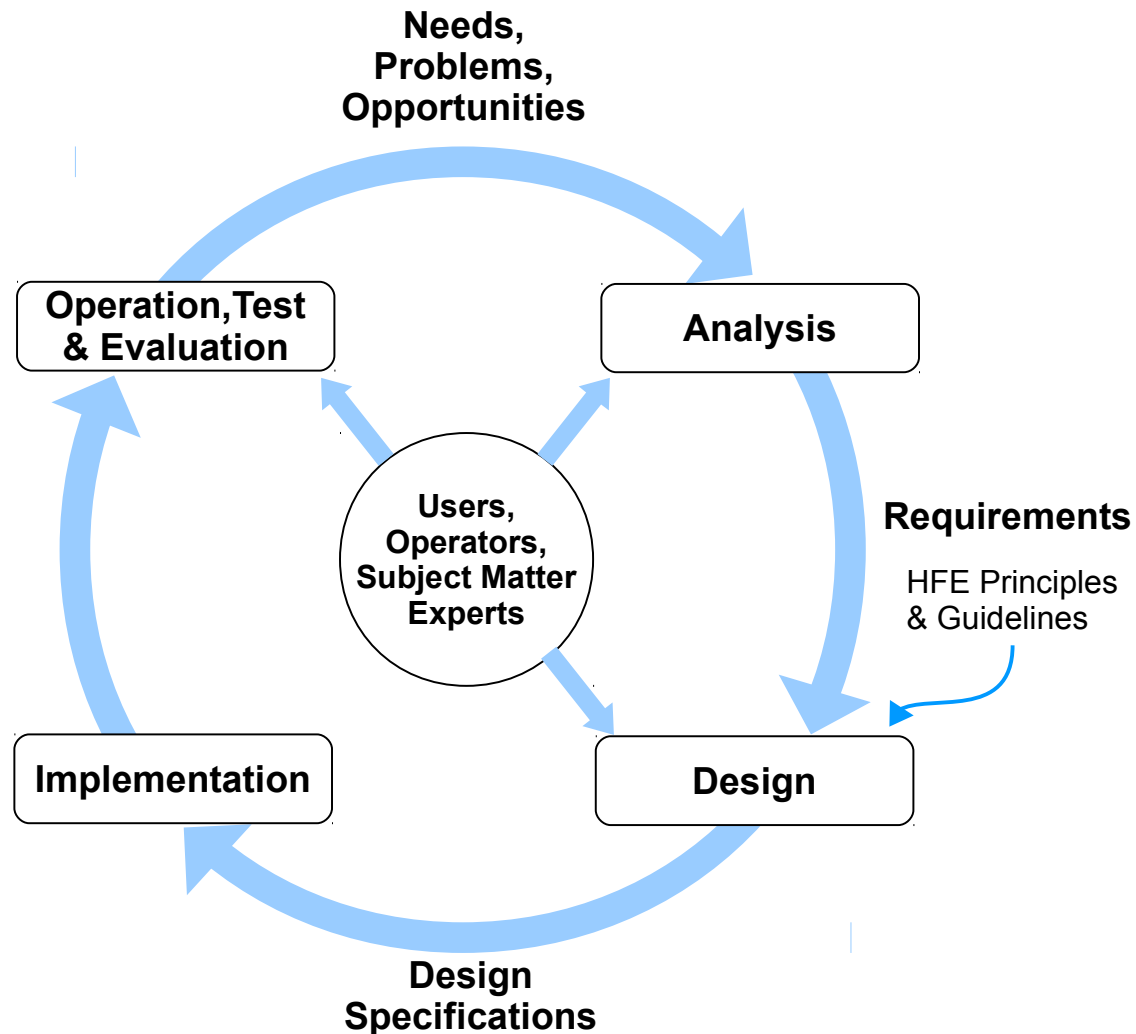
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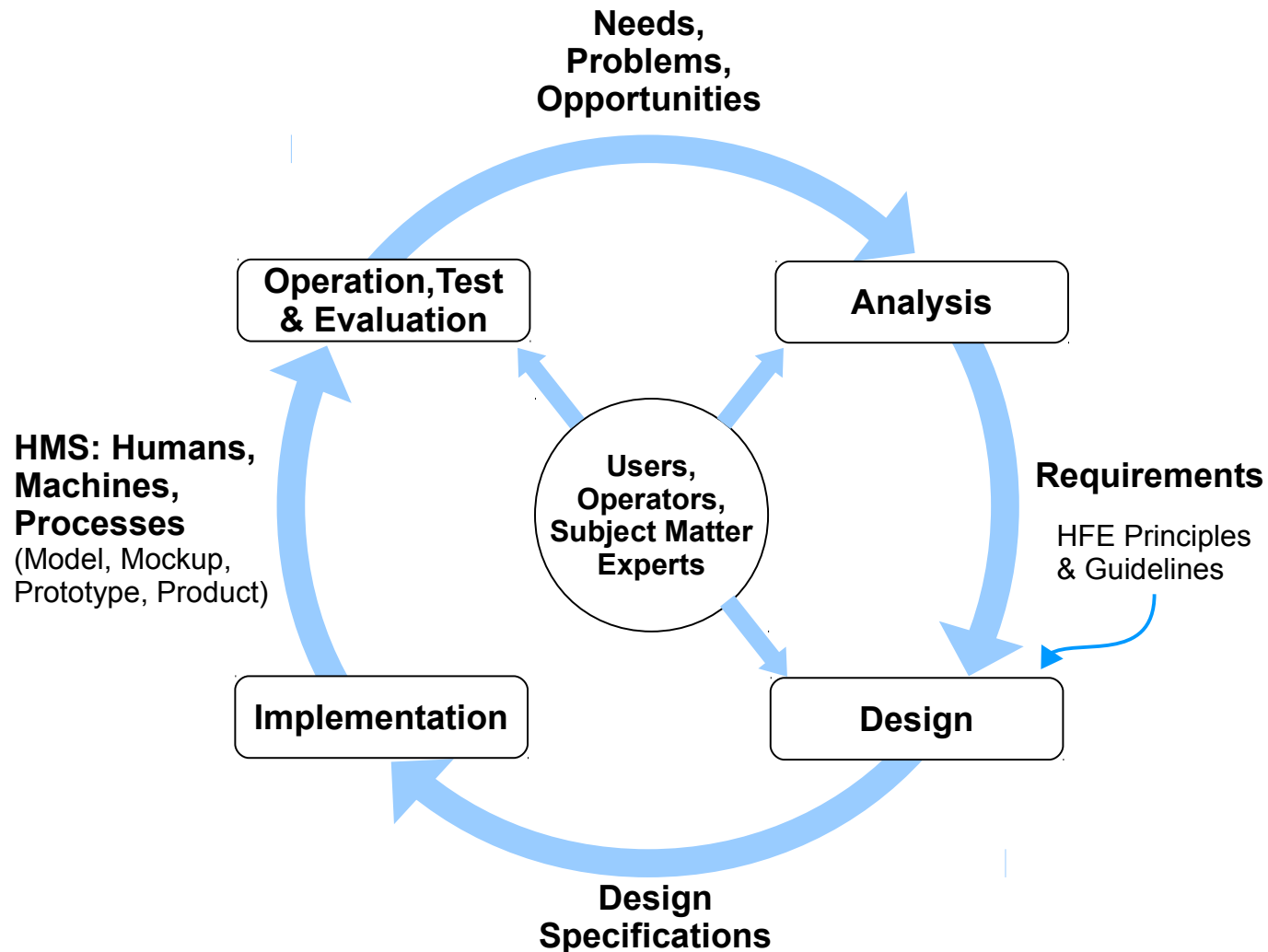
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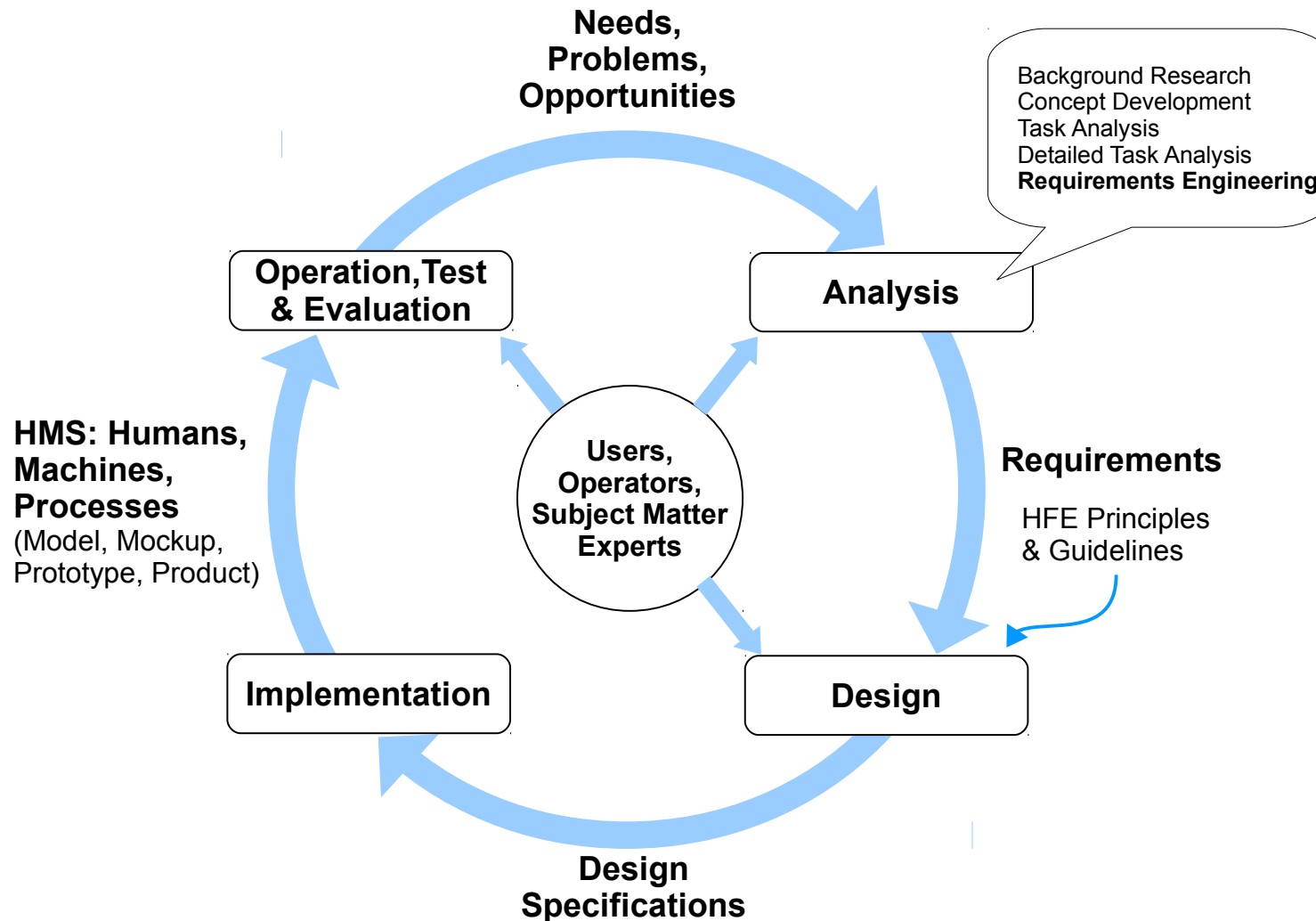
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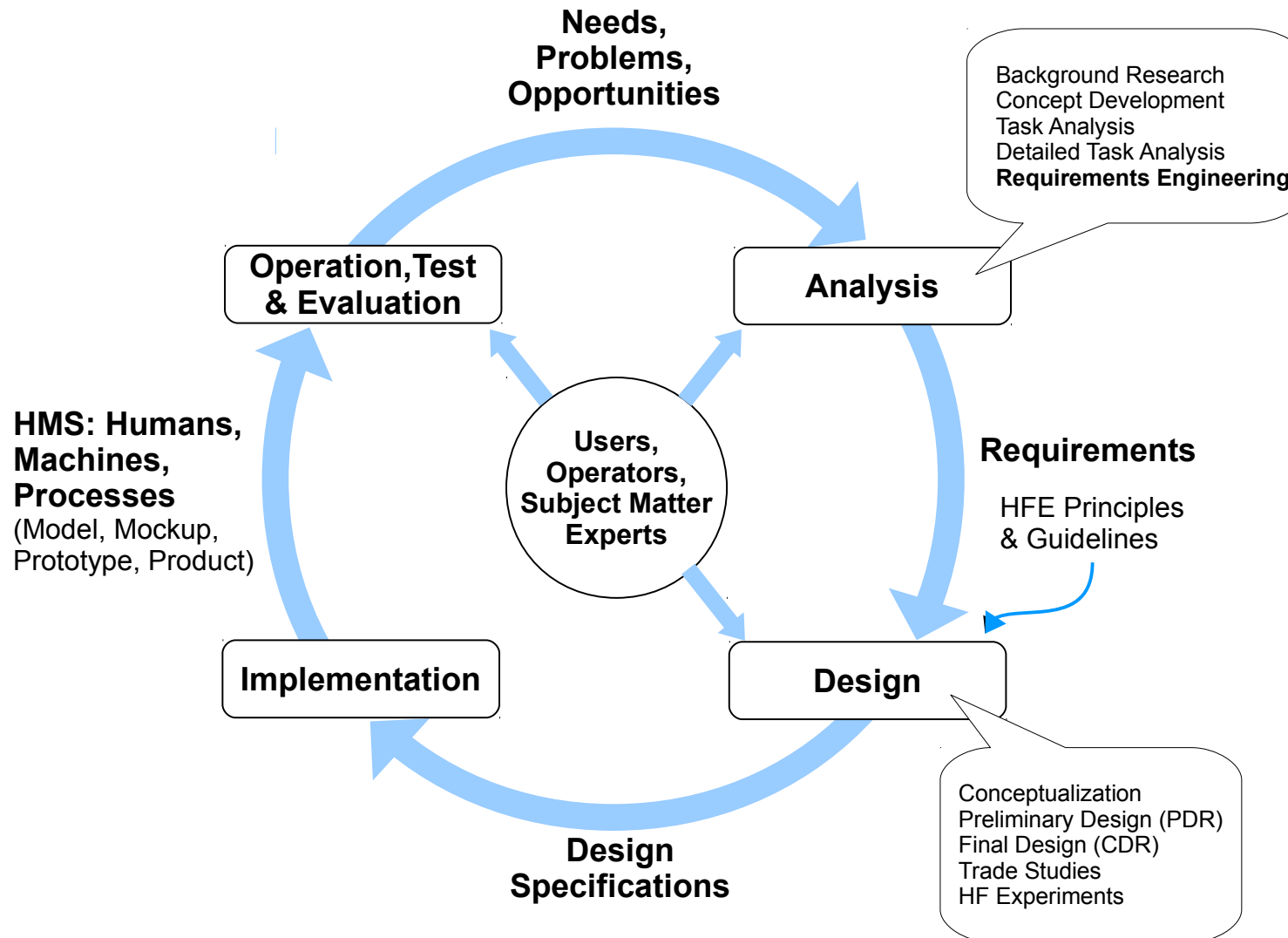
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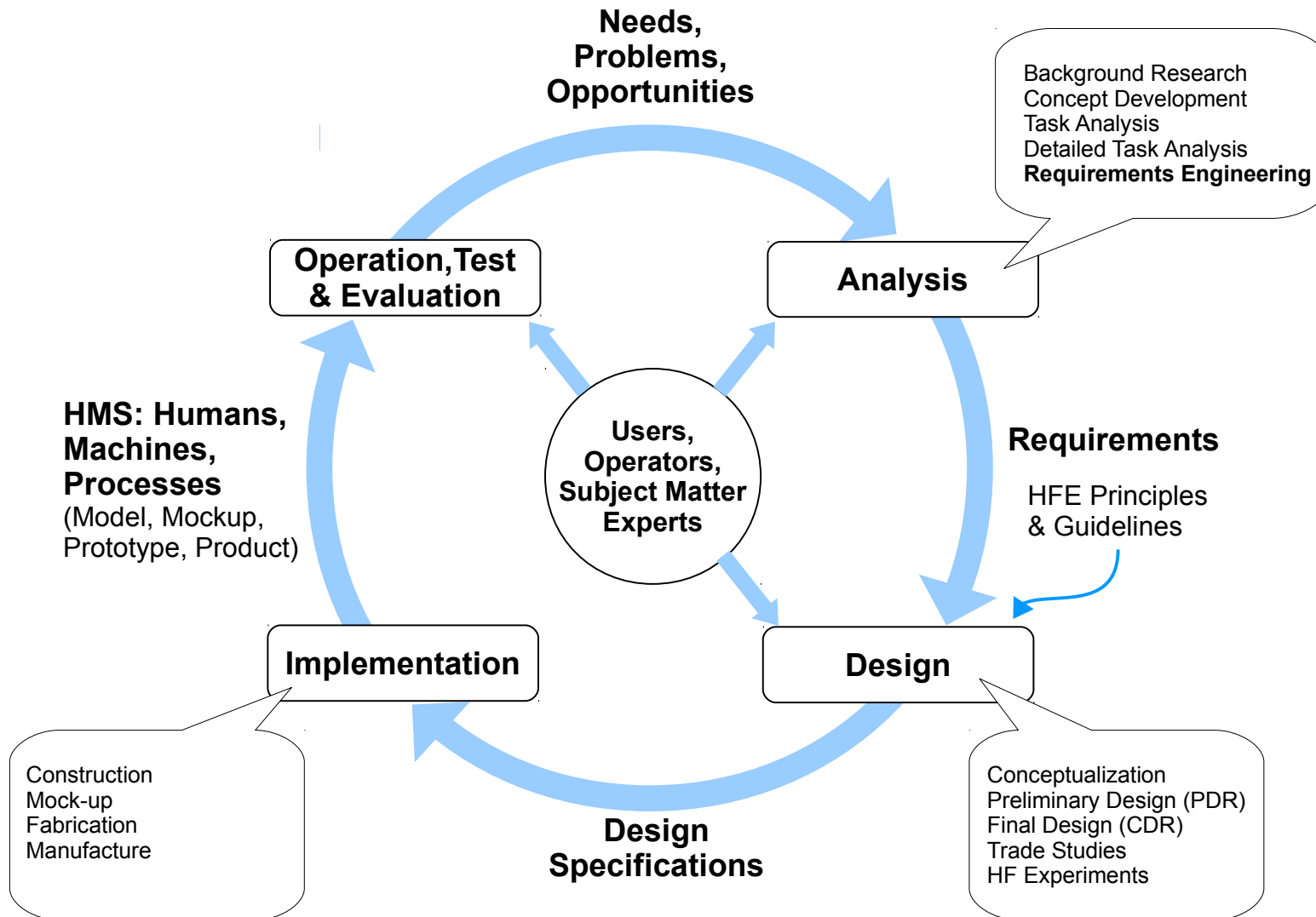
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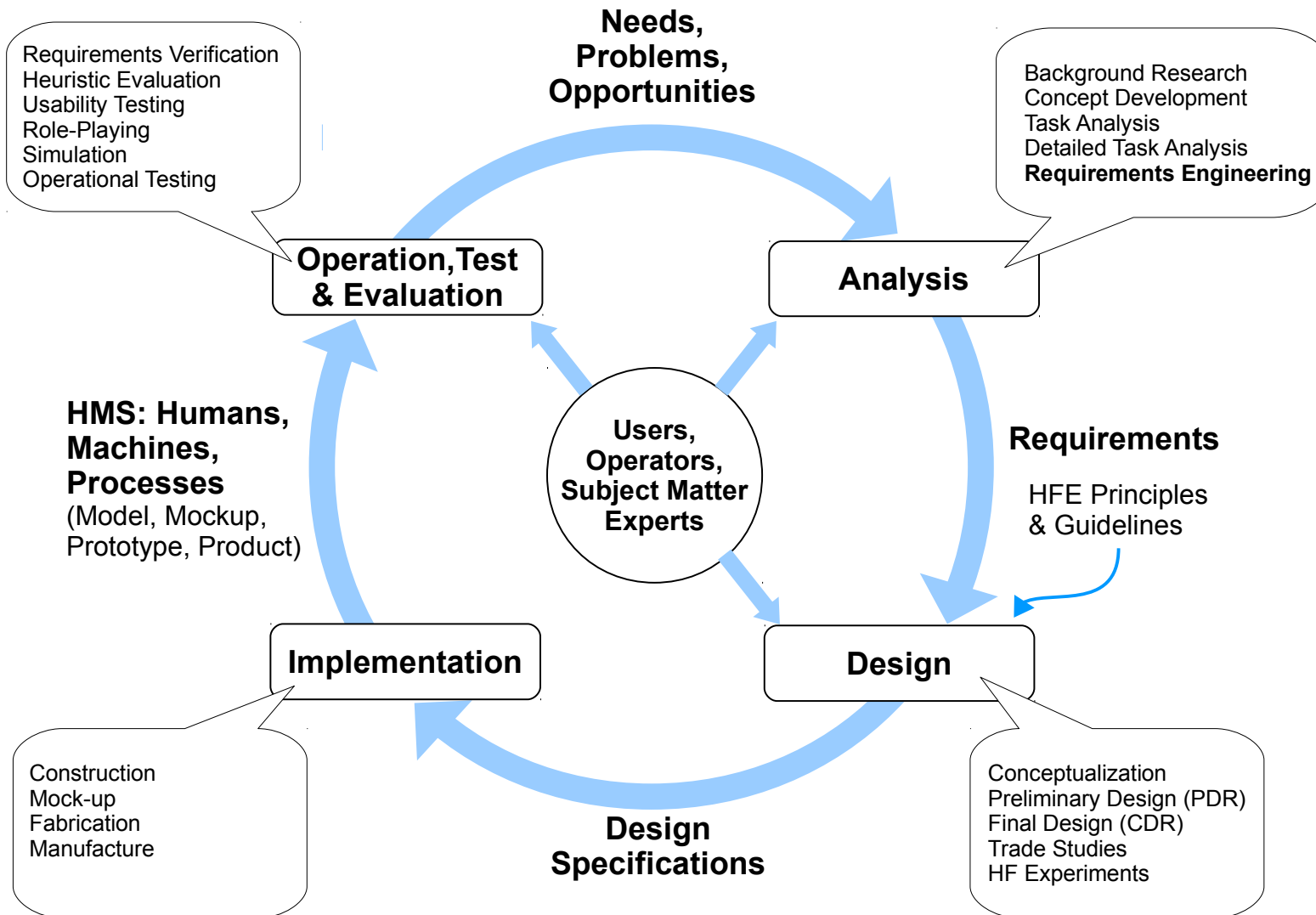
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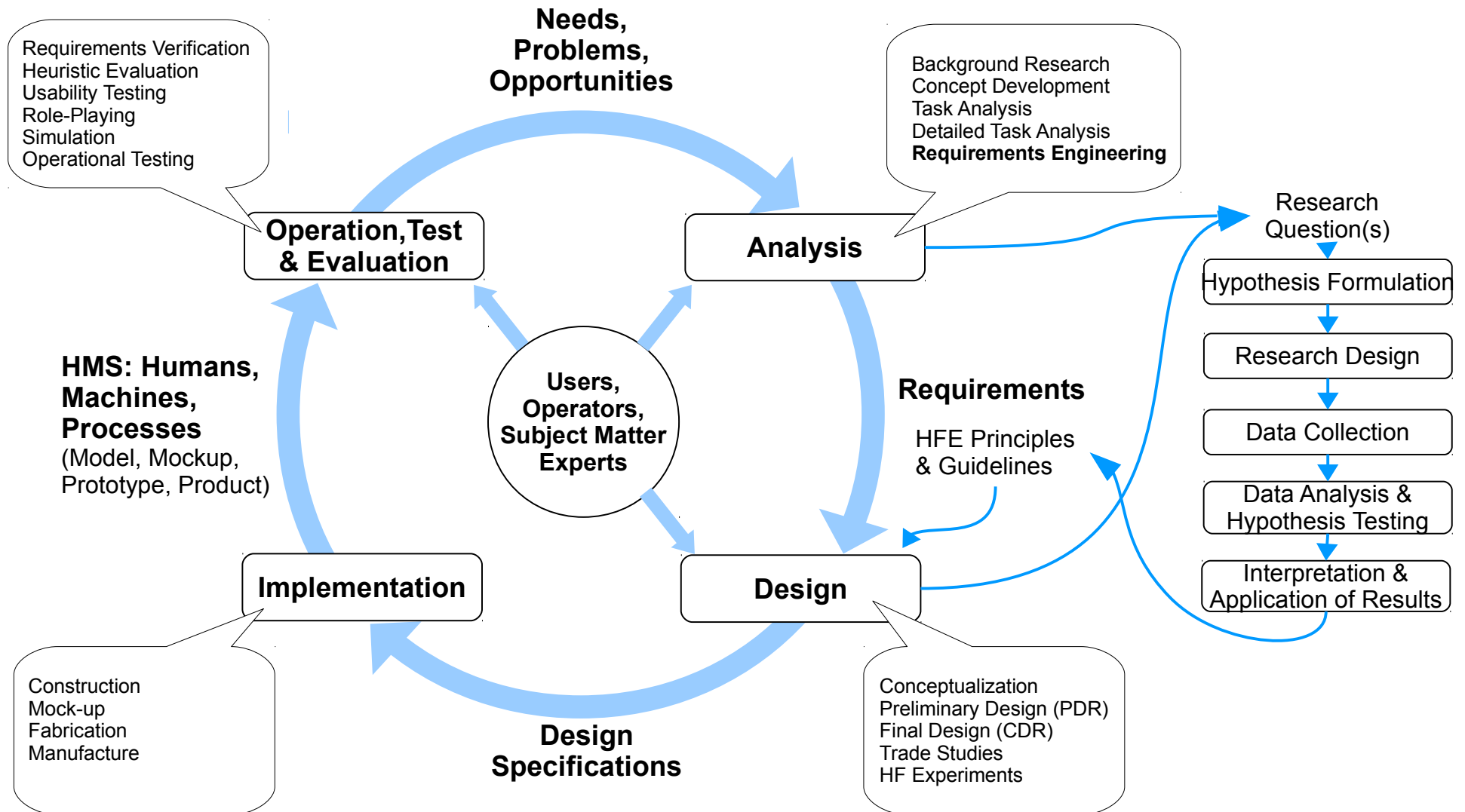
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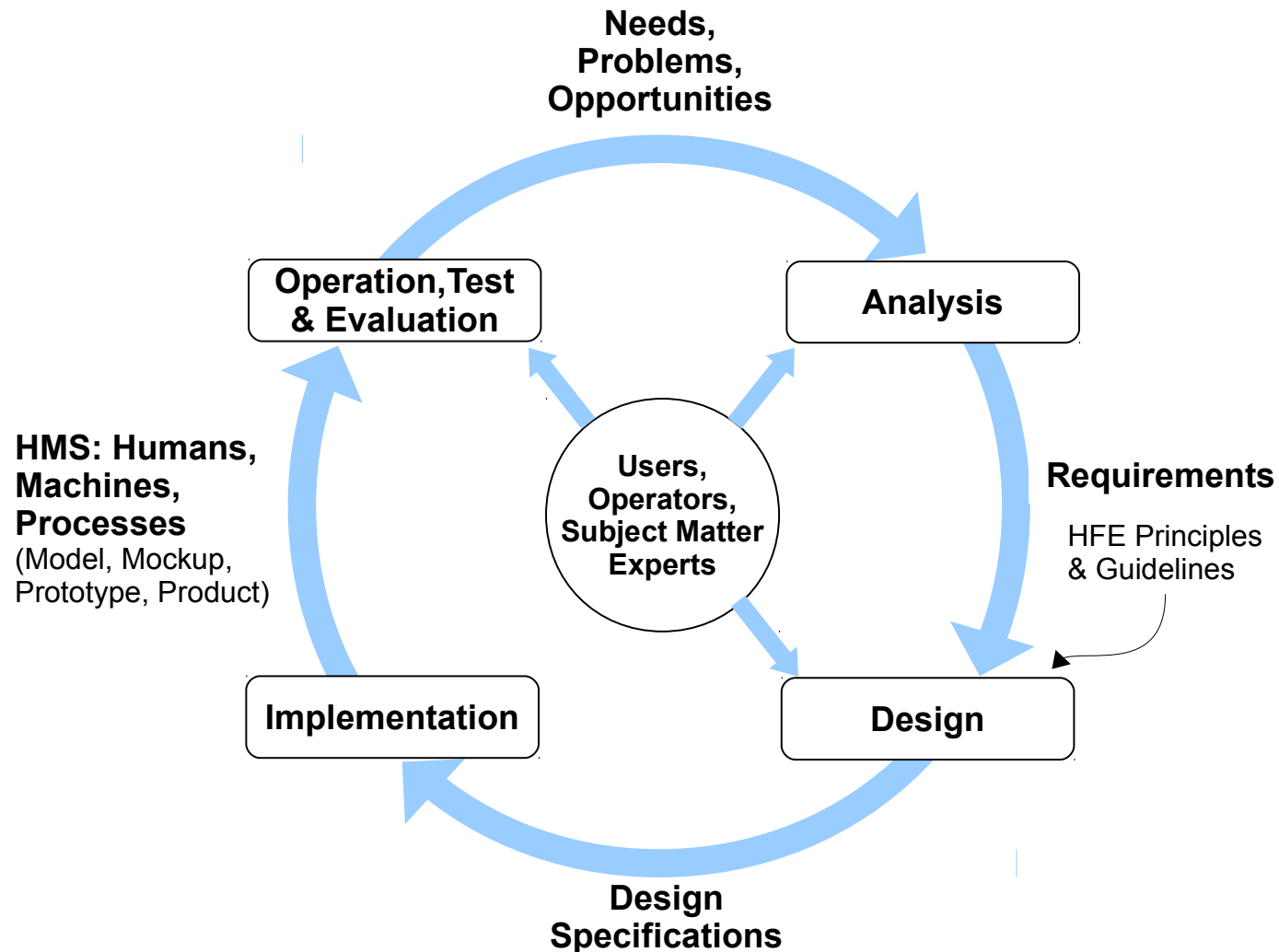
A User-Centered Human-Machine Systems Engineering Process



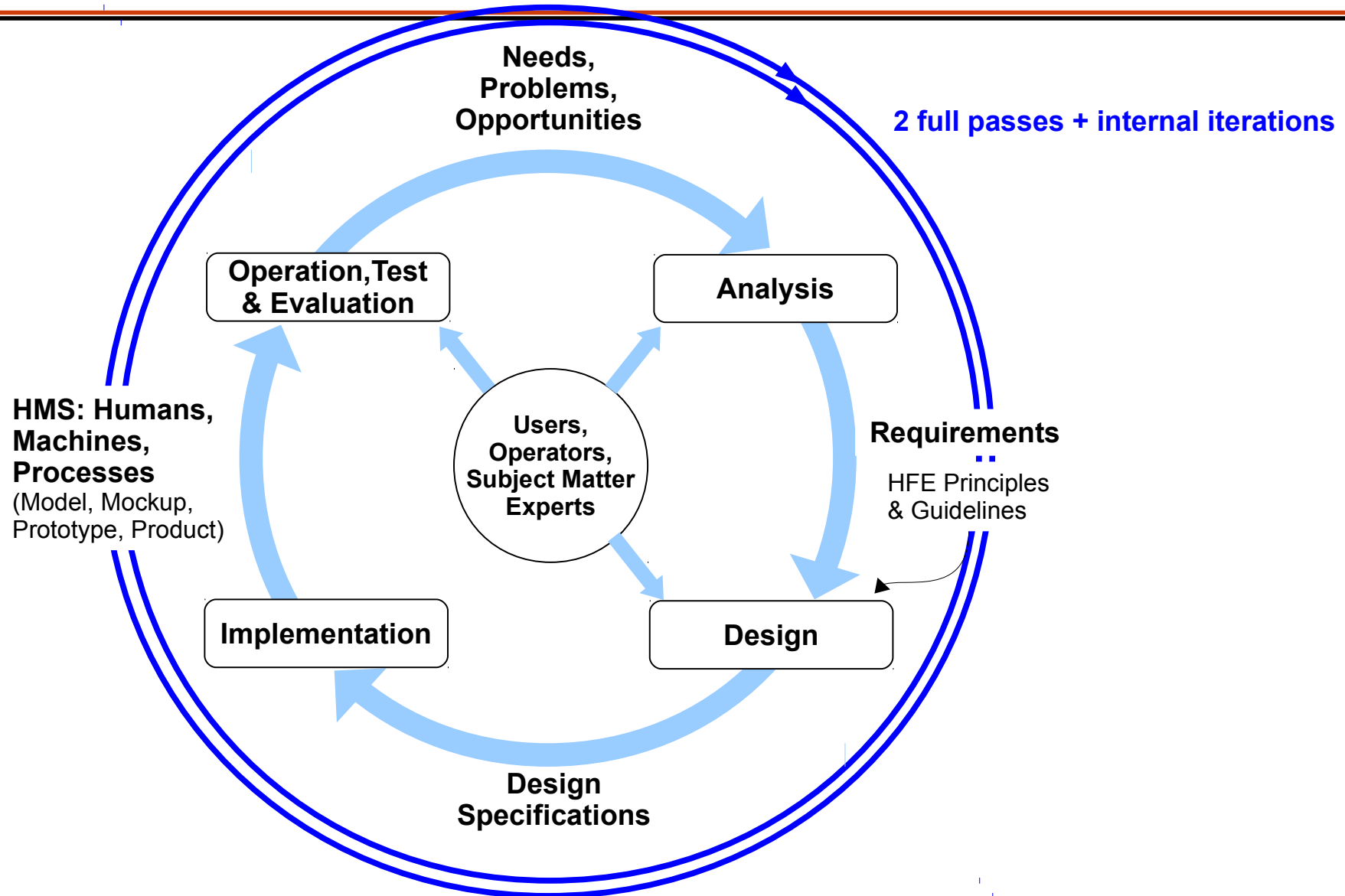
Example of the HMSE Process

Development of the Emergency Cesarean Delivery Facilitator (ECDF)

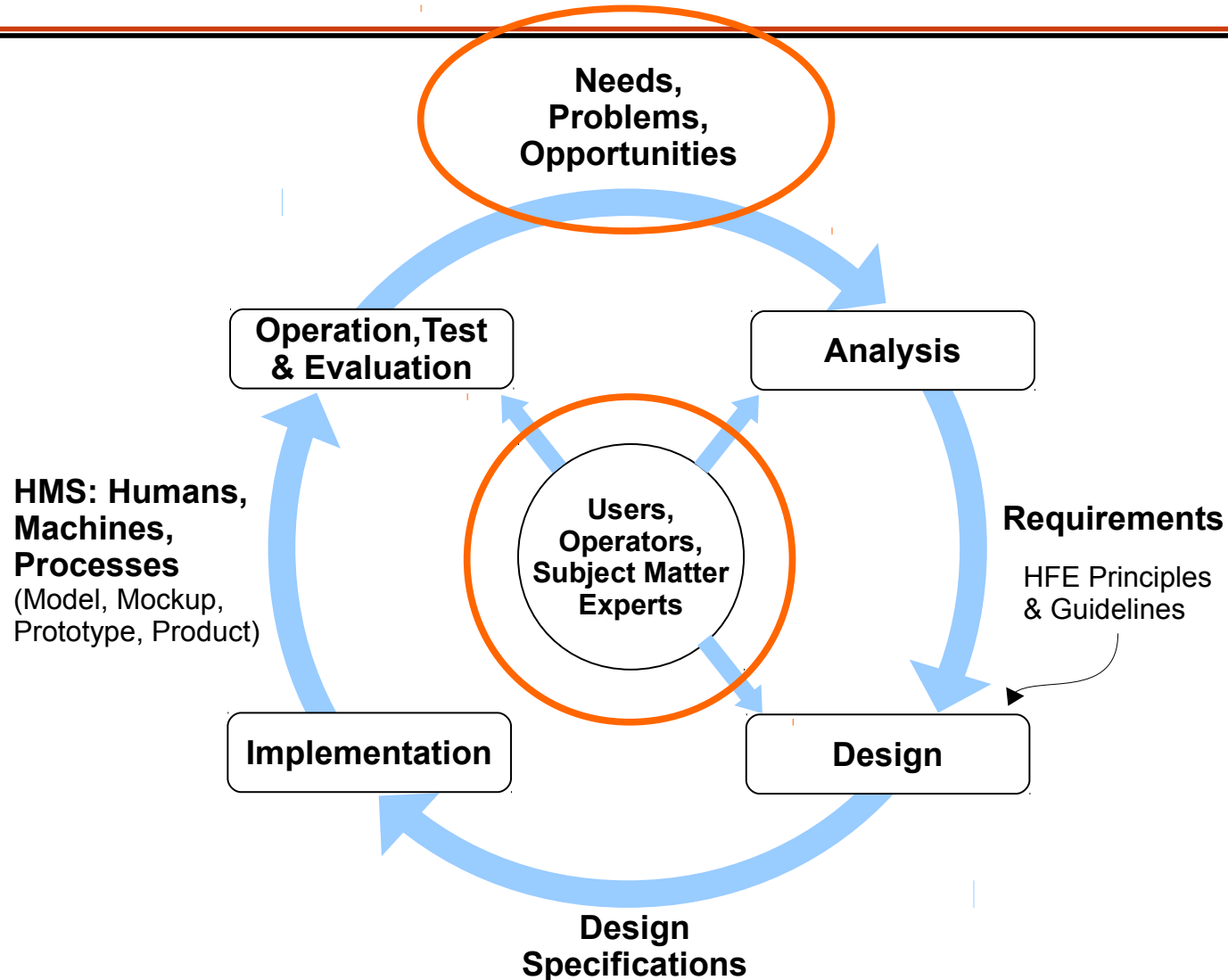
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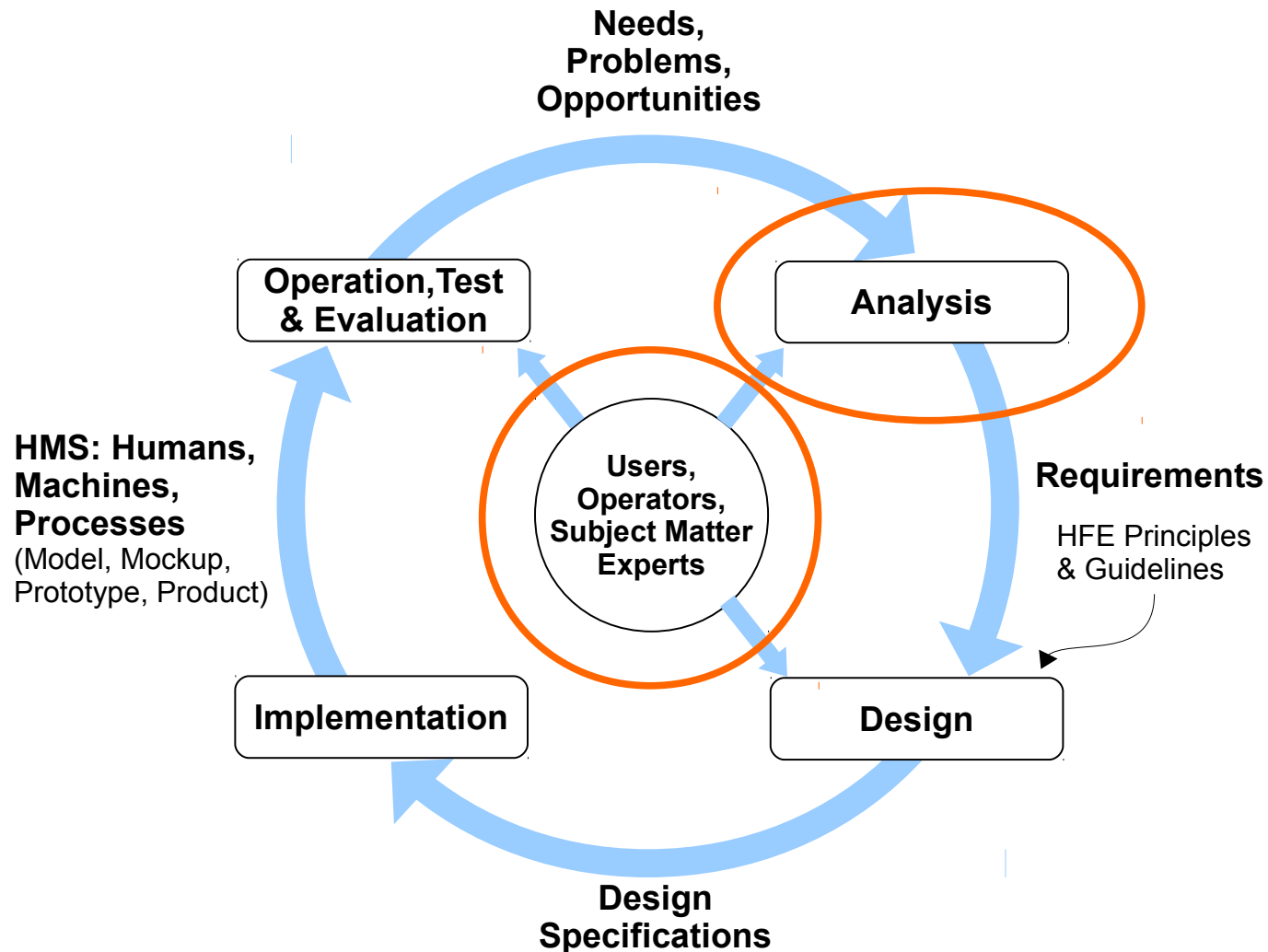
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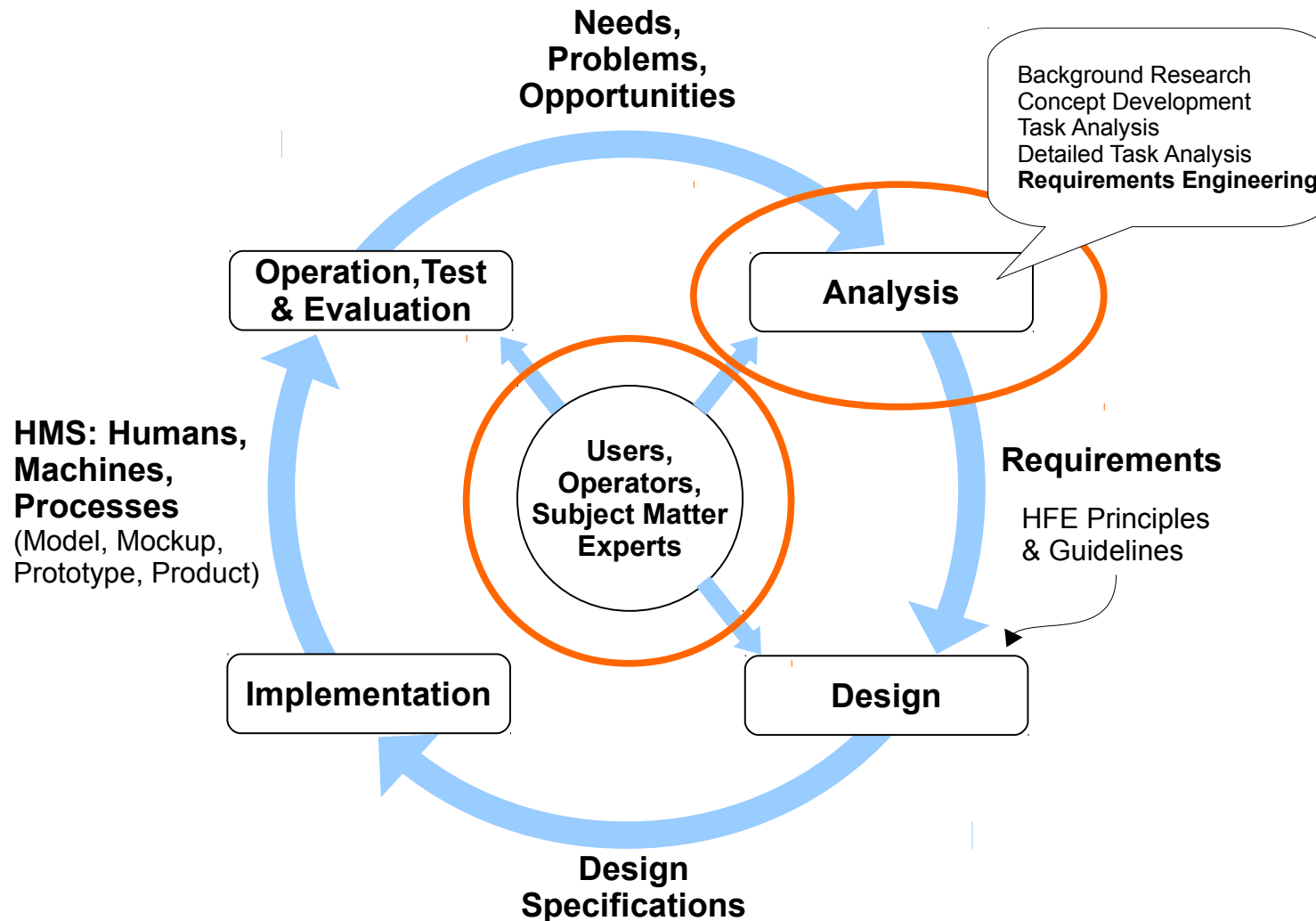
Background, Statement of Need

- 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

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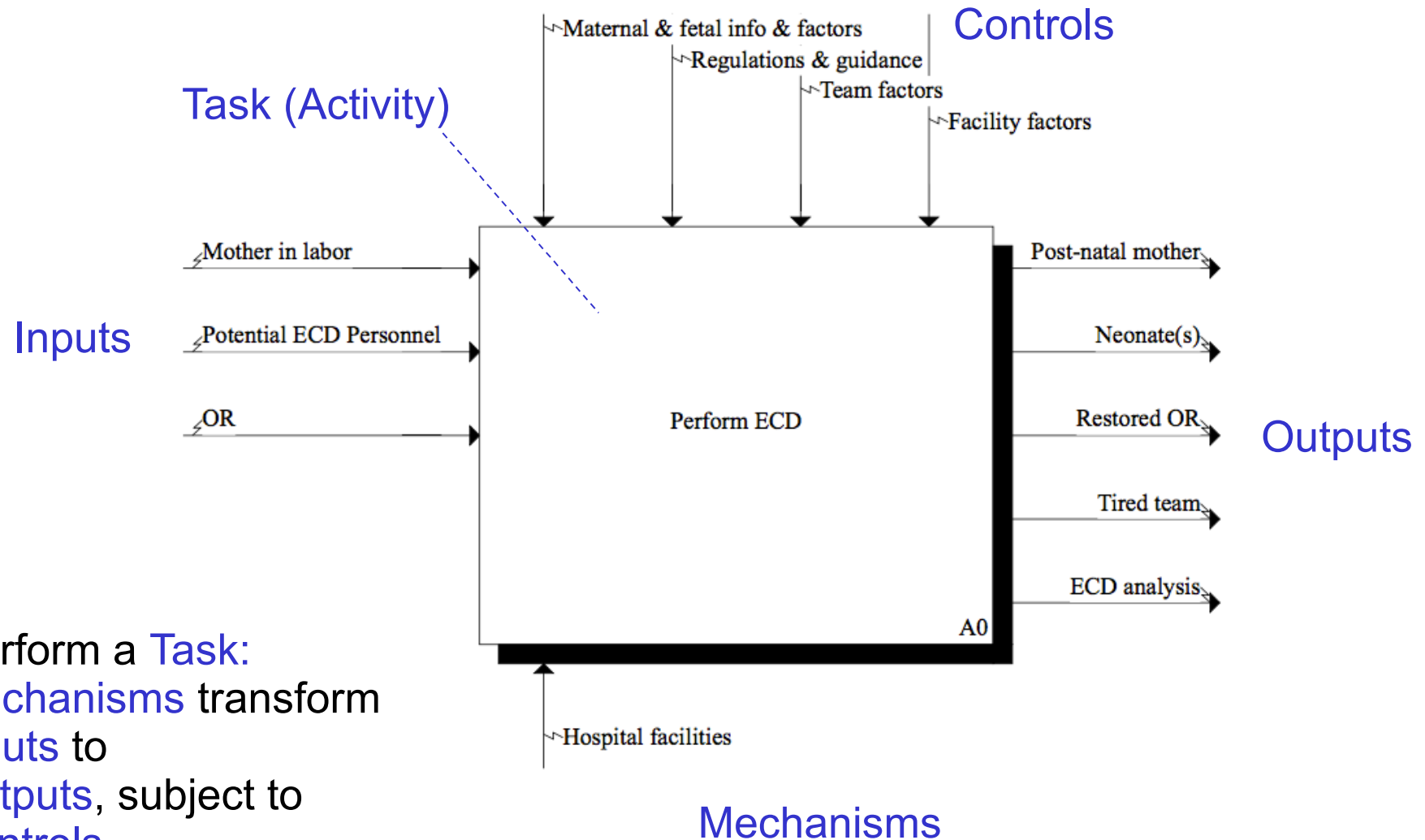


Hierarchical Task Analysis (partial): Perform Emergency Cesarean Delivery

- 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

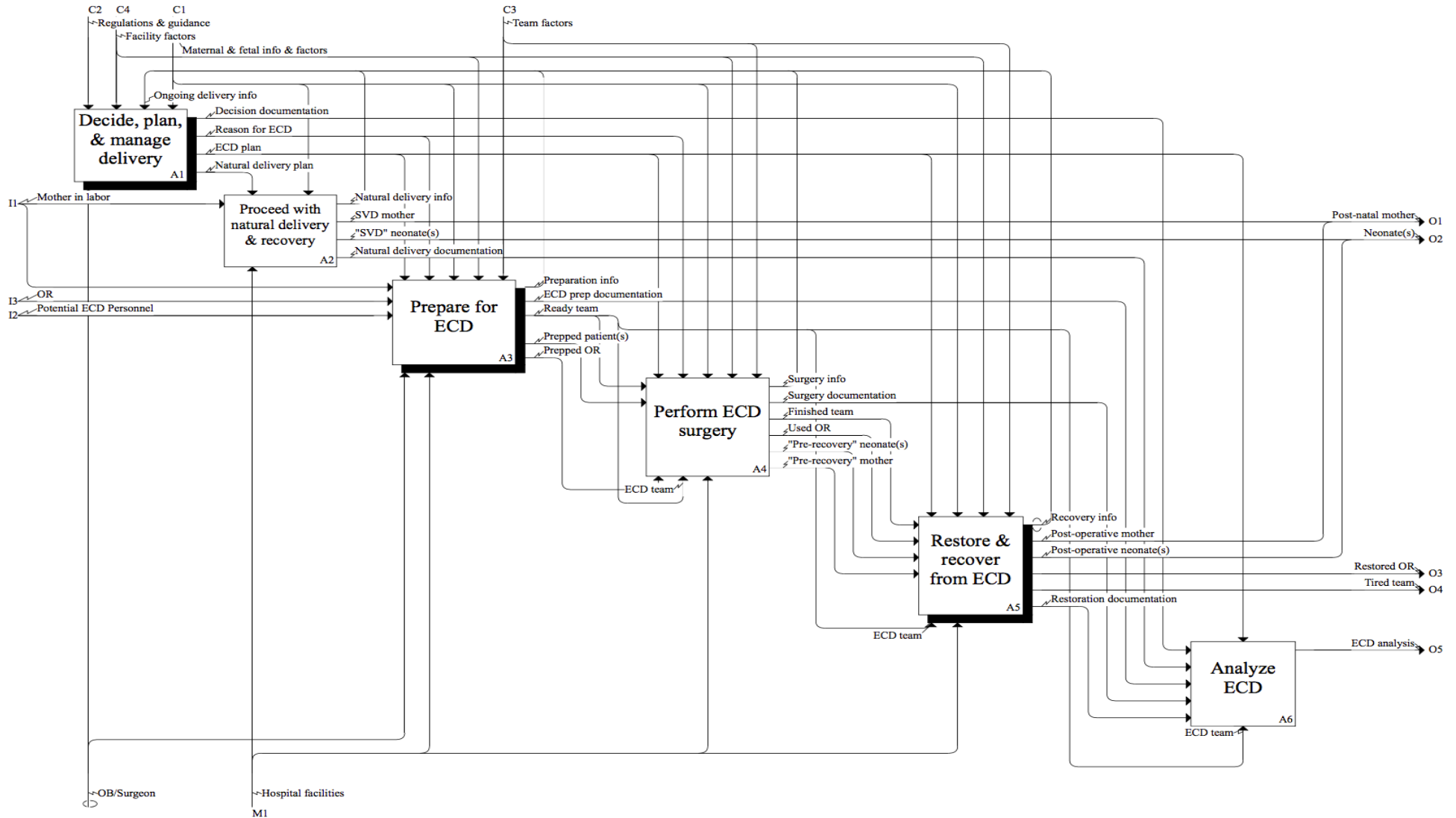
IDEF0 Task Analysis

Perform Emergency Cesarean Delivery (A-0 diagram)



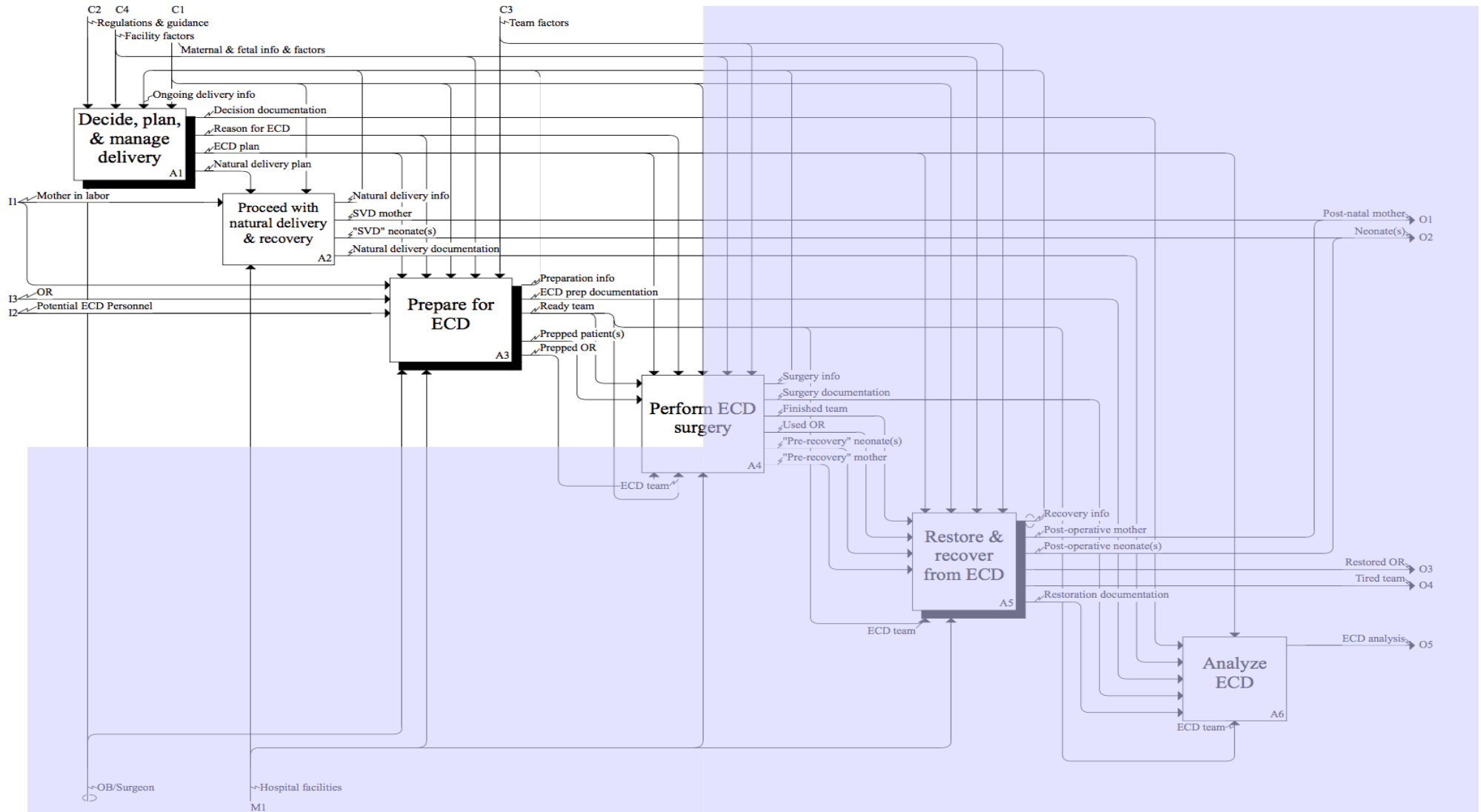
IDEF0 Task Analysis

Perform ECD (A0)



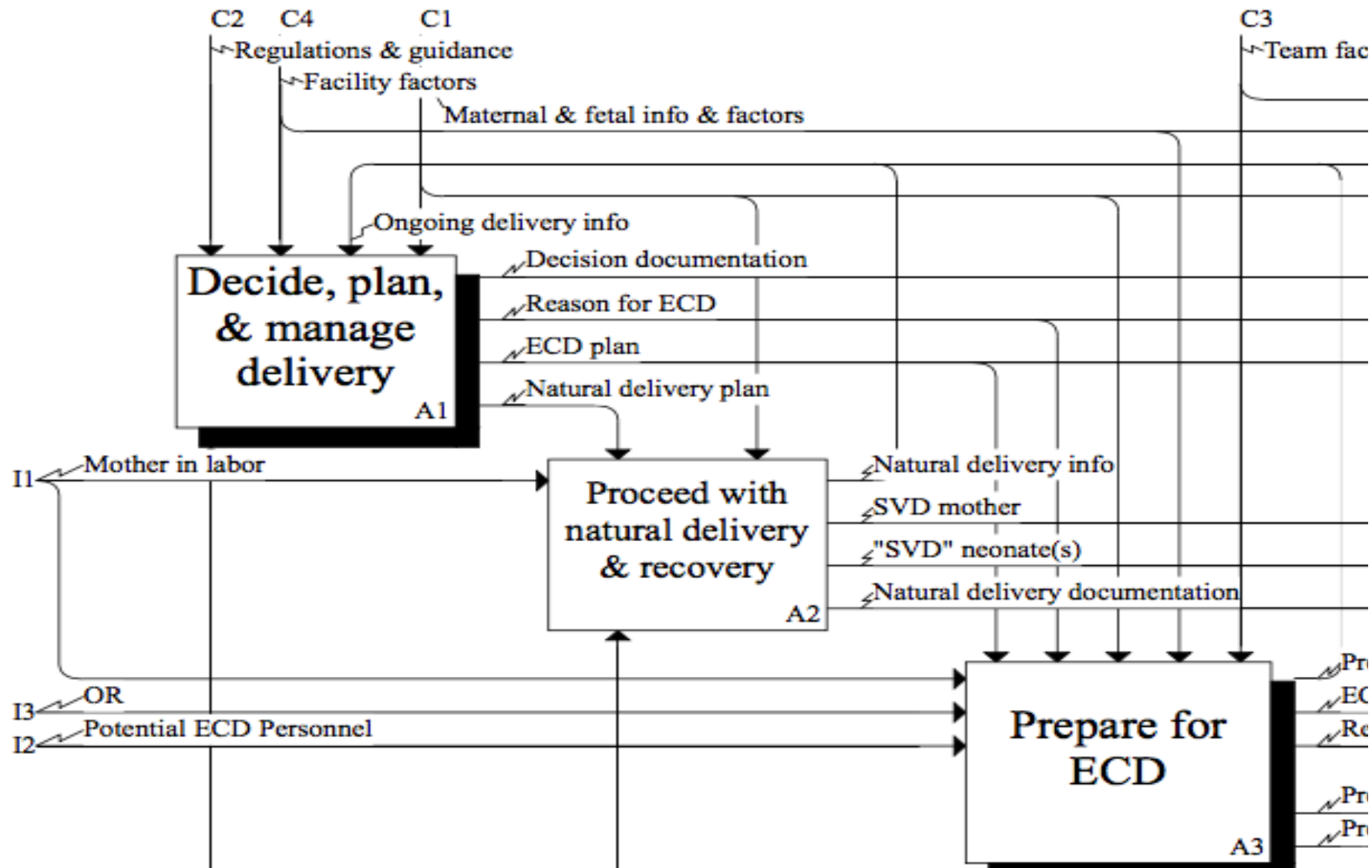
IDEF0 Task Analysis

Perform ECD (A0)



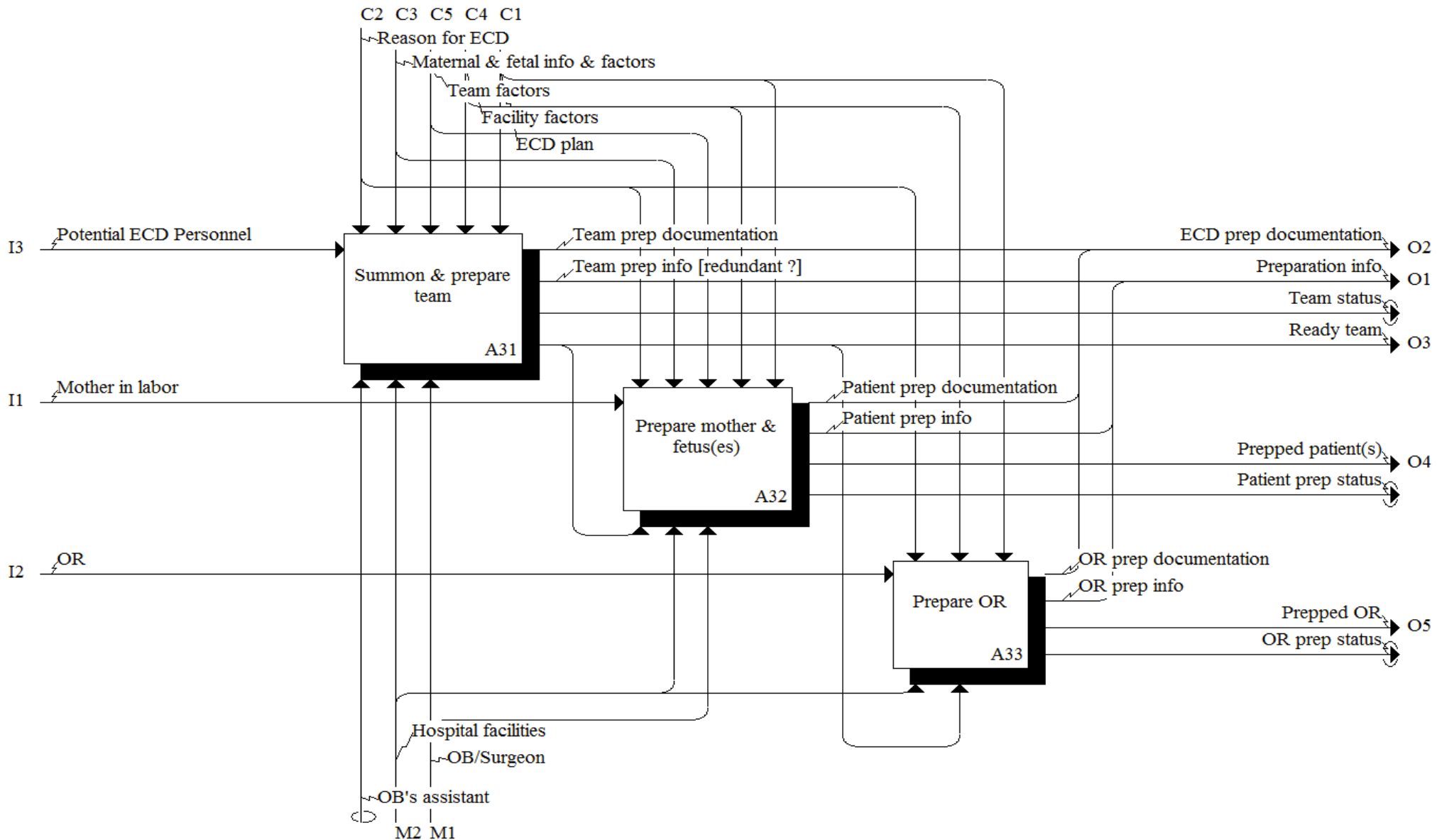
IDEF0 Task Analysis

Perform ECD (A0) Detail



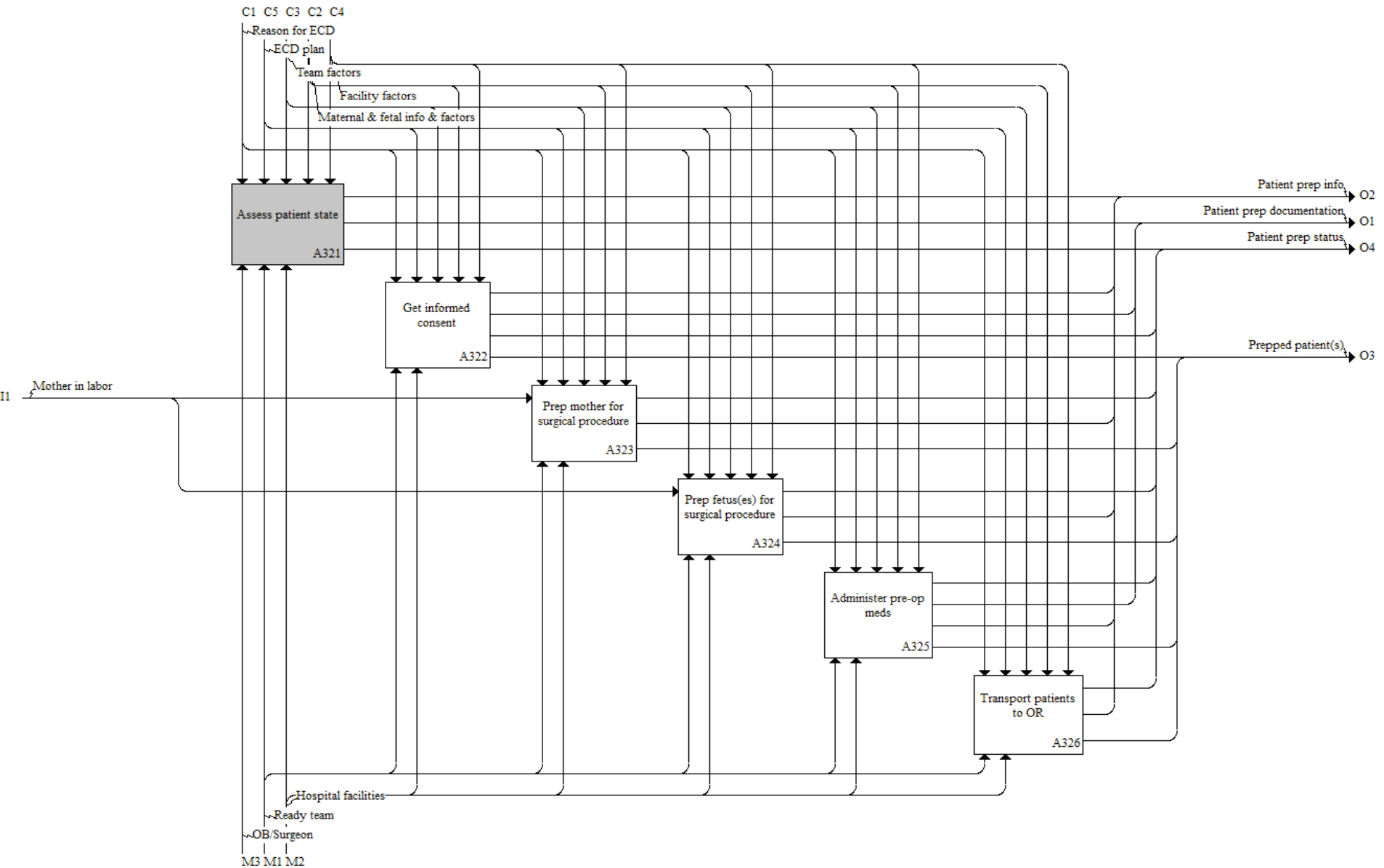
IDEF0 Task Analysis

Prepare for ECD (A3)

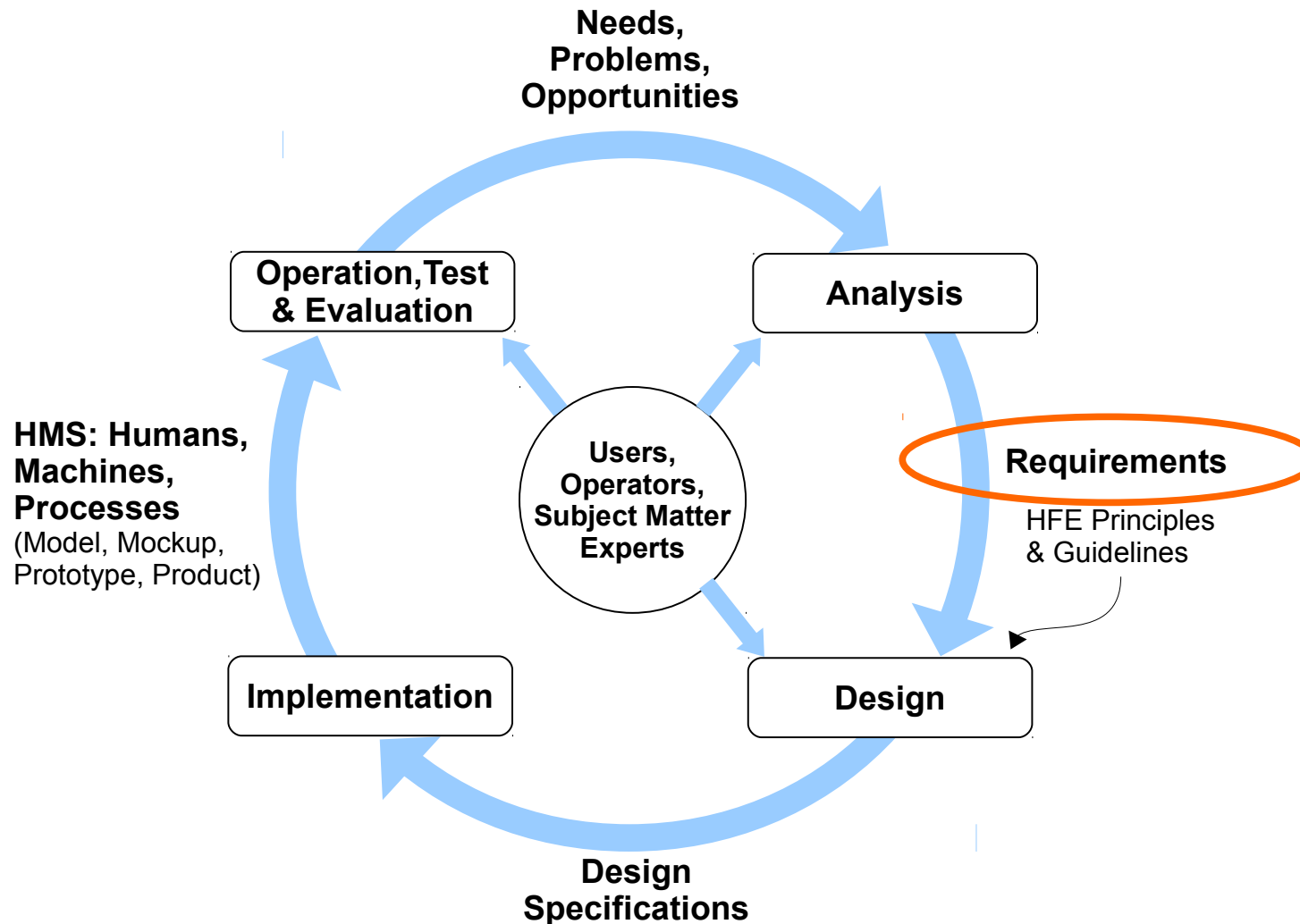


IDEF0 Task Analysis

Prepare mother & fetus(es) (A32)



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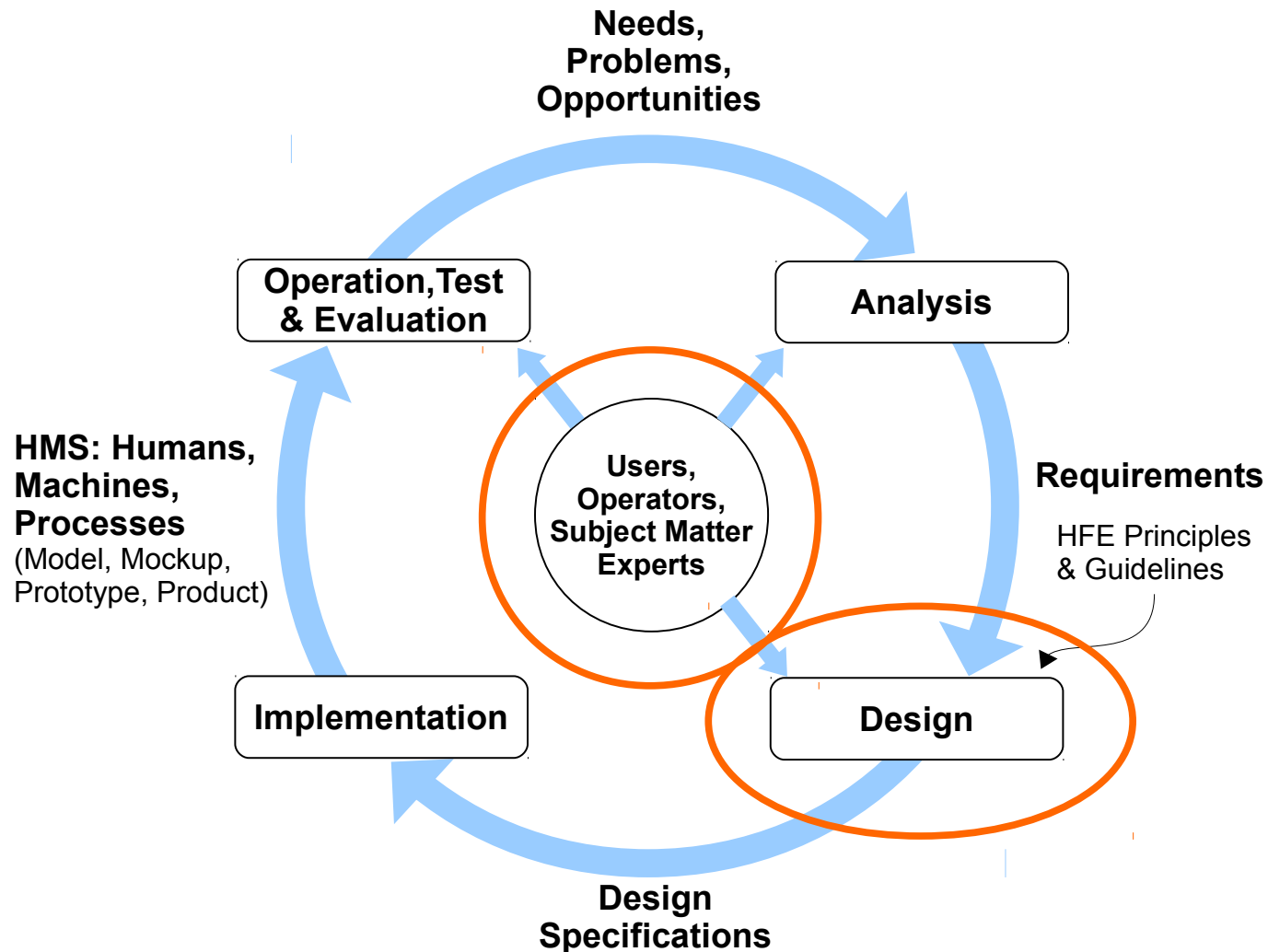
Some ECDF Functionality Requirements

- 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

- 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](#).

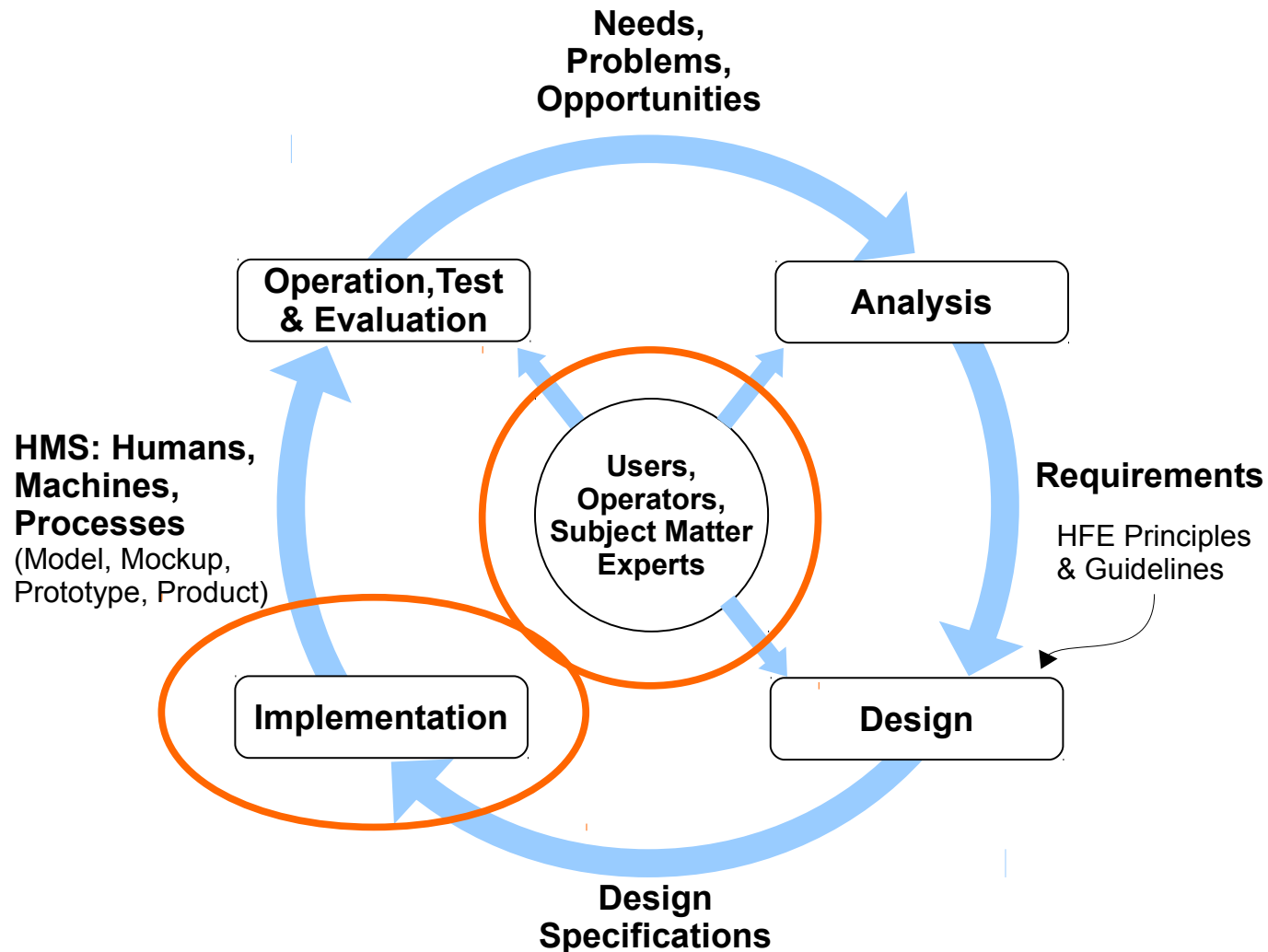
A User-Centered Human-Machine Systems Engineering Process



Design

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

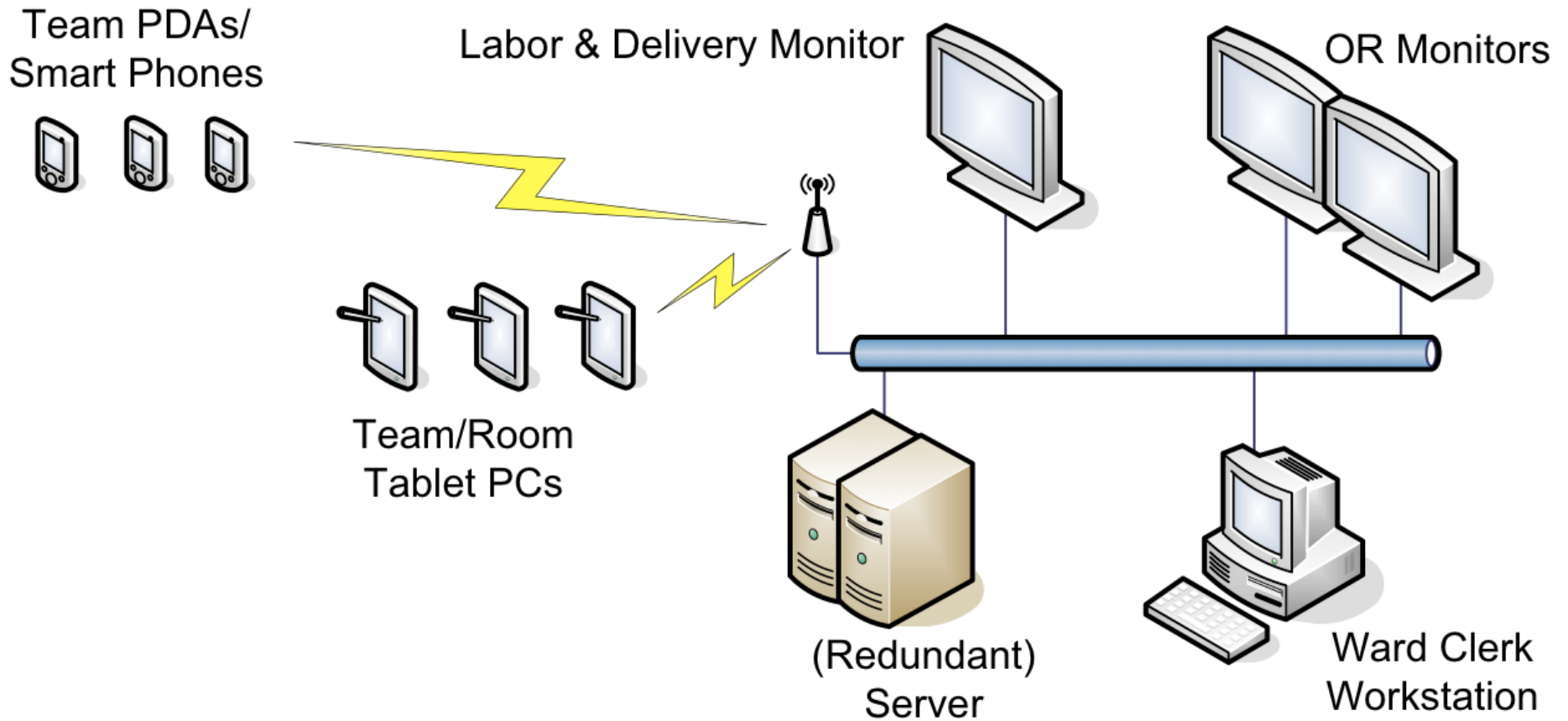
A User-Centered Human-Machine Systems Engineering Process



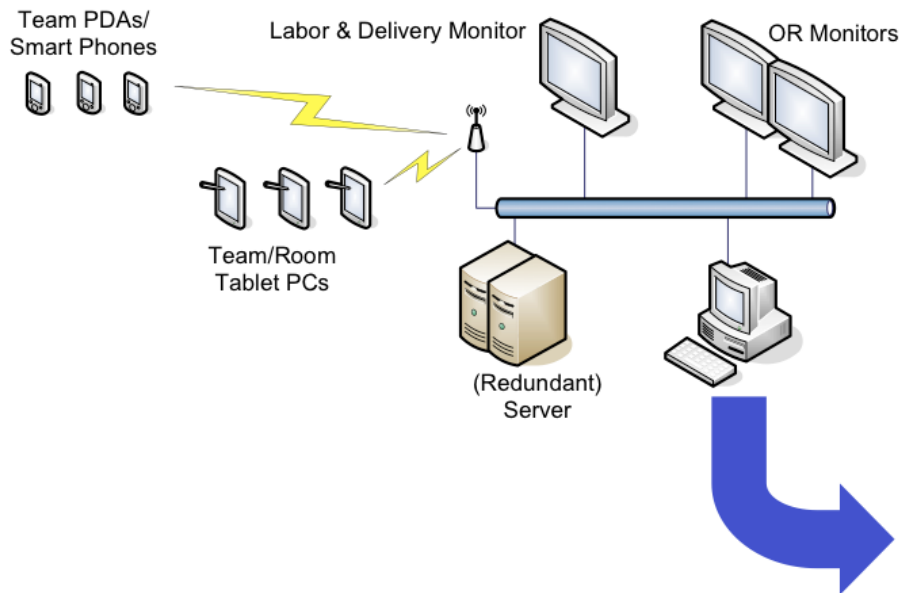
Prototype Implementation

- **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.

SUMMON CAESAREAN SECTION TEAM

Obstetrician:

Surgical Assistant/CNM-MidWife:

Anesthetist:

OB Nurse:

Scrub Nurse:

Circulating Nurse:

Family Practice Physician:

Respiratory Therapist:

Patient Status:

Patient ID:

Reason for CS:

Assembly Location:

Summons via PDAs/Smart Phones

Initial Summons Data

Classification: **Crash: Arrive within 10 min**

Patient Name: **Fields, Susan**

Reason for CS: **Failure to Progress**

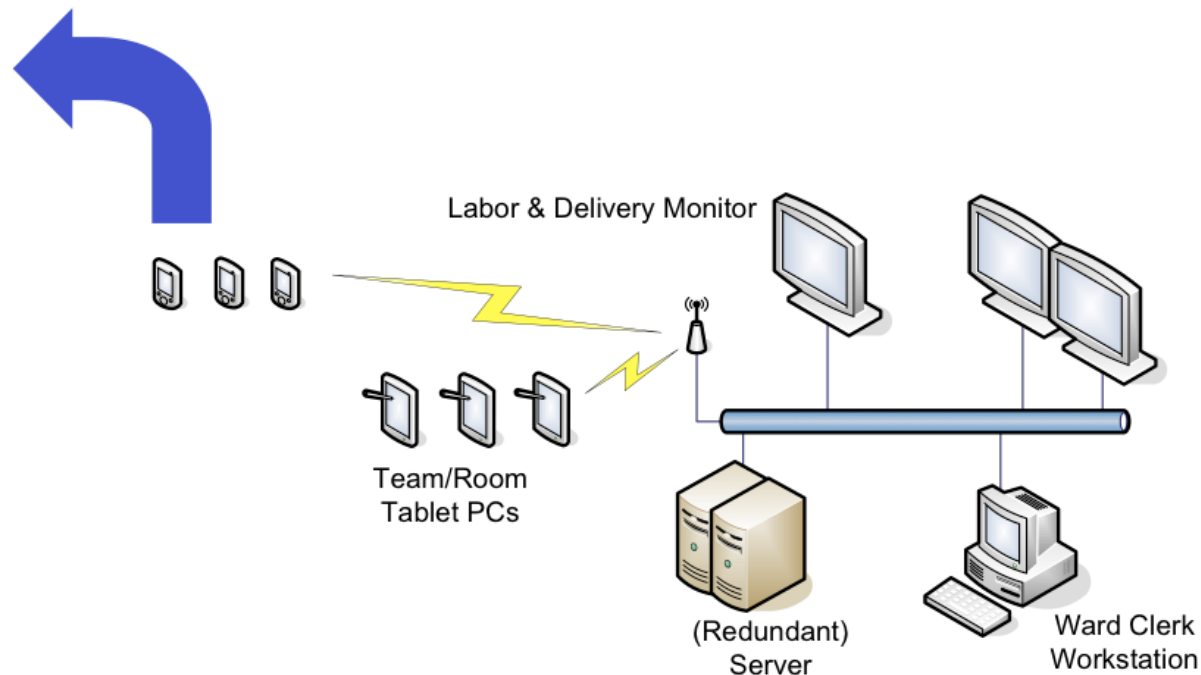
Location: **Operating Room 1**

Sorry. I am

Yes. I am

I am already

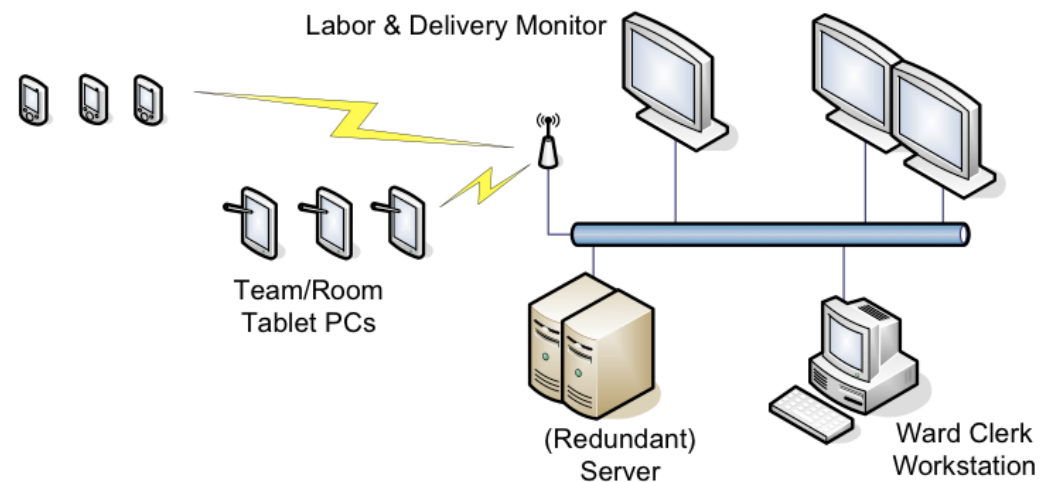
- Summons broadcast to all team members.
- Members respond.
- If unavailable, next on list summoned.



Team Status

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

•Available on all platforms to all team members.



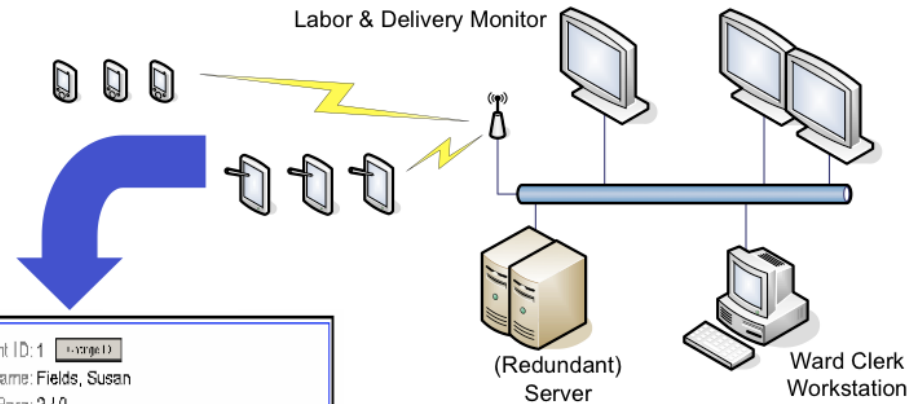
Patient Preparation With Tablet PCs Or PDAS

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

Patient State Assessed	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Informed Consent Signed	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
ID & Allergy Band Verified	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
IV and Oxygen Started	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Prophylactics & Antibiotics	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Bicitra Administrated	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Blood Drawn for CBC	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Foley Catheter Inserted	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Clipper Prep Performed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transported to OR	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Prepared for Anesthesia	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

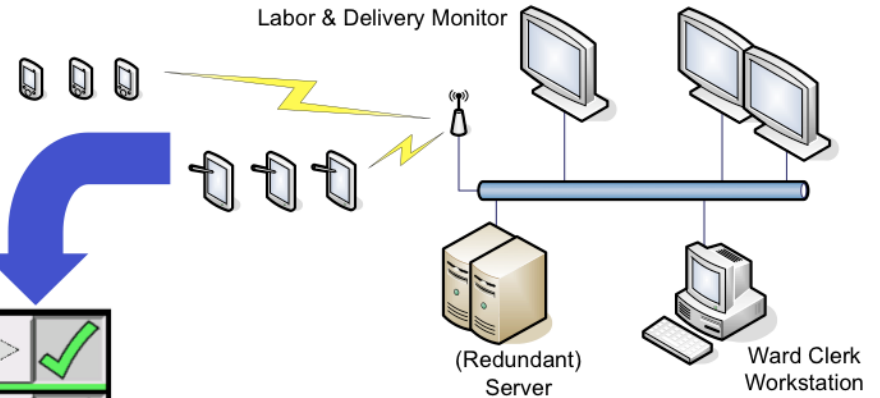


Patient ID: 1 <input type="text" value="Change ID"/>	
Patient Name: Fields, Susan	
Gravida & Para: 2 / 0	
Gestation Age: 37 Weeks	
Reason for CS: Failure to Progress <input type="button" value="File"/> <input type="button" value="Update"/> <input type="button" value="Cancel"/>	
Current Medications: None	
Allergies: NKDA	
Health During Pregnancy: No Major Problems	
Past Major Illnesses: None	
Membrane Rupture <input type="button" value="Edit"/>	
Time: 12:13	<input type="button" value="Update"/>
Color: Clear	<input type="button" value="Cancel"/>
Amount: 4 fl.oz.	
Cervix Position: Anterior	
Uterus Size: 10 inch	<input type="button" value="File"/>
Uterus Lie: <input type="text"/>	<input type="button" value="Update"/>
Presentation: <input type="text"/>	<input type="button" value="Cancel"/>
Dilatation: <input type="text"/>	
Contraction Interval: <input type="text"/> min <input type="button" value="File"/>	
Contraction Duration: <input type="text"/> sec <input type="button" value="Update"/>	
Contraction Intensity: <input type="text"/> <input type="button" value="Cancel"/>	



OR Preparation

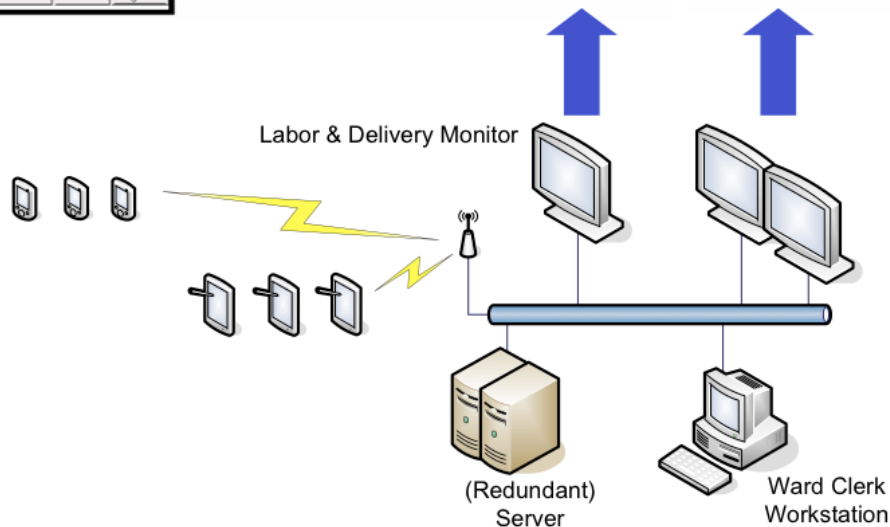
- Nurses & physicians prepare OR (checklist).
- Check (✓) completed items.
- Mark (▶) items in progress.
- Mark (X) problem items.



Anesthesia Machine	X	▶	✓
Anesthesia Cart	X	▶	✓
Suture Supplies	X	▶	✓
Prepared Baby Warmer	X	▶	✓
Oxygen & Airway Supplies	X	▶	✓
Surgical Equipment	X	▶	✓
Table & Lighting	X	▶	✓
Mayo Stand & Instruments	X	▶	✓
Neonatal Crash Cart	X	▶	✓
Forceps & KIWI	X	▶	✓

Labor & Delivery, OR Status Displays

Patient State Assessed	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<p>Patient ID: 10 Patient Name: Field, Susan Gravida & Para: 2 / 0 Gestation Age: 37 Weeks</p> <p>Reason for CS: Failure to Progress</p> <p>Current Medications: None Allergies: NKDA Health During Pregnancy: No Major Problems Past Major Illnesses: None</p> <p>Membrane Rupture Time / Color / Amount: 12:13 / Clear / 4 fl.oz.</p> <p>Cervix Position: Anterior Uterus Size: 3 inch Uterus Lie: Longitudinal Presentation: Breech (Butt) Dilation: 1 cm</p> <p>Contraction Interval: 11 min Contraction Duration: 11 sec Contraction Intensity: Medium</p>	Obstetrician	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Anesthesia Machine	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Informed Consent Signed	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Dey, Jane	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Anesthesia Cart	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
ID & Allergy Band Verified	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Surgical Assitant/CNM-Midwife	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Suture Supplies	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
IV and Oxygen Started	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Short, Bill	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Prepared Baby Warmer	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Prophylactics & Antibiotics	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Anesthetist	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Oxygen & Airway Supplies	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Bicitra Administrated	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Long, Mary	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Surgical Equipment	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Blood Drawn for CBC	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		OB Nurse	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Table & Lighting	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Foley Catheter Inserted	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Cole, Jack	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Mayo Stand & Instruments	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Clipper Prep Performed	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Scrub Nurse	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Neonatal Crash Cart	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Transported to OR	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Kim, Linda	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Suction Vacuum	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Prepared for Anesthesia	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>		Circulating Nurse	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>				
					Lee, Ken	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>				
					Family Practice Physician	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>				
					Jones, Gary	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>				
				Respiratory Therapist	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>					
				Gage, Cindy	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>					



Status displays also available on

- Tablets
- PDAs
- Desktops

Prototype Implementation

- **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
 - Web browsers
- **Prototype 4** (NIH SBIR grant with Bauer Labs, 2014-15):
Storyboard
 - Storyboard: screenshots in scenario

Prototype 3.0/3.1

The screenshot shows the 'Emergency Cesarean Delivery Facilitator' web application in a Mozilla Firefox browser. The page title is 'Emergency Cesarean Delivery Facilitator'. The main content area is titled 'Summon Team' and includes the text: 'The following medical personnel will be summoned on the call'. Below this text are several dropdown menus for selecting medical personnel:

- Obstetrician: Ken Masters
- Surgical Assistant: Timmothy Lawson
- Anesthetist: Solomon Graves
- OB Nurse: Alice Harbin
- Scrub Nurse: Simon Grimble
- Circulating Nurse: Jason Treen
- Family Practice Physician: Chris Bluth
- Respiratory Therapist: Joel Hayter

Below the personnel selection is a 'Summons Data' section with input fields for 'Patient First Name', 'Patient Last Name', 'Patient Status', and a dropdown for 'Assembly Location' (set to OR 1).

The screenshot shows the 'Emergency Cesarean Delivery Facilitator' web application in a Mozilla Firefox browser. The page title is 'Emergency Cesarean Delivery Facilitator'. The main content area is titled 'Patient Checklist' and contains a table with columns for 'Patient State Assessed', 'Patient Medical Information', and 'OR Checklist'. The table lists various tasks and their completion status:

Task	Patient State Assessed	Patient Medical Information	OR Checklist
Informed Consent Signed	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
ID & Allergy Band Verified	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
IV and Oxygen Started	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Prophylactics & Antibiotics	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Bicitra Administrated	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Blood Drawn for CBC	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Foley Catheter Inserted	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Clipper Prep Performed	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Transported to OR	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Prepared for Anesthesia	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

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

Prototype 4

ECD Dashboard

Patient id: 145, 0-neg, 5'3", Fetus: 37w / 3d, Patient: 31 yrs

Comments: Allergic to antibiotics

Clock: 07:35 Since initiation

Name of OB: Laura McD, Cause of ECD: Placenta Previa

Chat

OB	✓	▼	•	ETA	Status
OB Nurse	✓	▼	•	4min	REPLIED
Surgical Ass.	✓	▼	•	2min	REPLIED
Anesthetist	✓	▼	•	ON SITE	Read
Scrub Nurse	✓	▼	•	15min	REPLIED
Circulating Nurse	✓	▼	•	3min	Read
Physician	✓	▼	•	3min	REPLIED
Respiratory Ther.	✓	▼	•	ON SITE	REPLIED

Buttons: Terminate, Add Staff

Mobile App Alert:

ALERT
RESPONSE ACKNOWLEDGED
Sent: 1:36 minutes ago
ECD - STAT
@PROVIDENCE-Milwaukee LR#1

Are you (select one):

- 1 Already In-House
- 2 On My Way
- Unavailable

Call Center Desk

What is your Estimated Time to Arrival (ETA)?

1--5--10--15--20

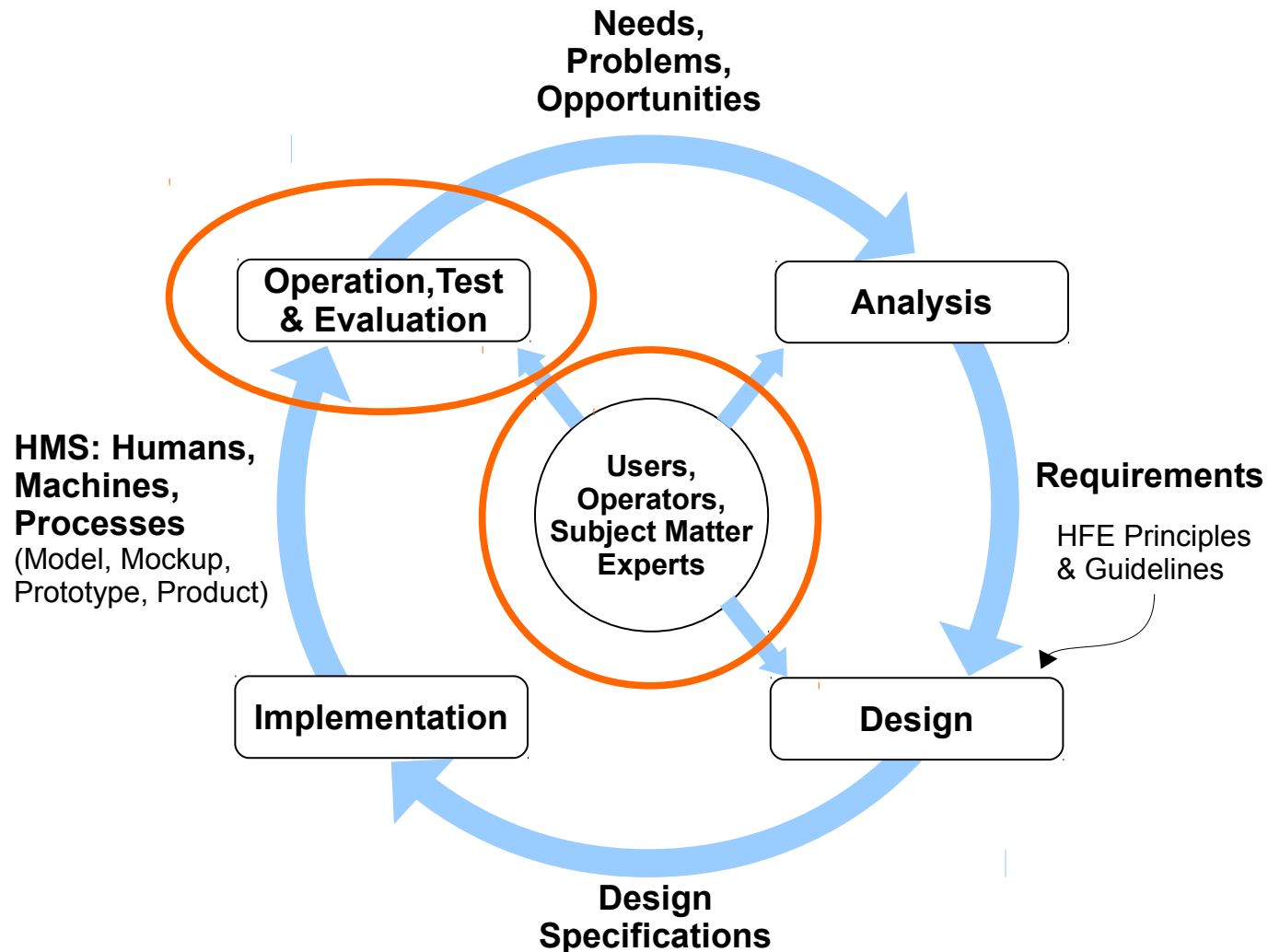
ETA: 11 Minutes Confirm

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

Main interactions :

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

A User-Centered Human-Machine Systems Engineering Process



Operation and Evaluation of Prototype 2

- 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

(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

