RAPPORT TECHNIQUE

Réf. ISAE/DISC/RT2019/1

RAPPORT BENCHMARK FORMATIONS INGÉNIERIE SYSTÈMES

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1. INTRODUCTION

Ce benchmark a eu lieu dans le cadre du volet « formation et enseignement » de la Chaire CASAC (Conception et Architecture de Systèmes Aériens Cognitifs) à l'ISAE-SUPAERO avec Dassault Aviation. Ces activités s'insèrent dans les programmes de l'ISAE-SUPAERO, dans une perspective internationale, en association avec ses partenaires académiques. Deux objectifs principaux sont poursuivis : la mise en place d'une sensibilisation sur la notion d'architecte de systèmes aériens en s'appuyant principalement sur l'existant du cursus ingénieur de l'ISAE-SUPAERO et la conduite d'une réflexion sur les formations d'architecte de systèmes aériens en formation initiale et formation continue. L'objectif est de former les futurs ingénieurs capables d'anticiper l'évolution des systèmes, qui seront plus "cognitifs", c'est à dire capables de s'adapter et d'apporter assistance à l'équipage.

La conduite d'une réflexion sur les formations d'architecte de systèmes aériens en formation initiale et formation continue s'appuie sur

- Une analyse des besoins et attentes des industriels (piloté par Dassault Aviation)
- Un benckmarking des formations existantes au niveau national et international (piloté par ISAE-SUPAERO)
- Bilan des formations proposées à l'ISAE-SUPAERO et proposition d'évolution si besoin

Ce rapport reporte sur le benchmarking des formations existantes. La synthèse de cette action, en prenant en compte l'analyse des besoins et attentes des industriels et le benchmarking des formations existantes au niveau national et international fera objet d'un rapport séparé avec des recommandations sur les formations proposées à l'ISAE-SUPAERO.

1.1. LA NOTION « D'ARCHITECTE DE SYSTEMES AERIENS »

La notion d'architecte de systèmes aériens sous-entend la notion d'architecte de systèmes, un aspect de l'ingénierie qui n'est pas ou que très peu adressé dans les troncs commun du cycle ingénieurs ISAE-SUPAERO.

Le but des activités d'architecture de système est de définir une solution complète basée sur des principes, des concepts et des propriétés logiquement liés et cohérents les uns avec les autres. L'architecture de la solution a des caractéristiques et des propriétés satisfaisant, autant que possible, aux problèmes exprimés par un ensemble d'exigences (système et au cours du cycle de vie) qui sont résolues grâce à plusieurs disciplines (mécanique, électronique, hydraulique, logiciels, services, procédures, activité humaine…).

L'architecture du système est abstraite, axée sur la conceptualisation, globale et centrée sur la mission et les concepts du cycle de vie du système. Il se concentre également sur la structure de haut niveau des systèmes et des éléments du système. Il aborde les principes architecturaux, les concepts, les propriétés et les caractéristiques du système d'intérêt. Il peut également être appliqué à plus d'un système, formant dans certains cas la structure commune, le modèle et l'ensemble d'exigences pour les classes ou les familles de systèmes similaires ou connexes.

La formation d'ingénieur ISAE-SUPAERO va jusqu'à la conception et la réalisation concrète des systèmes. Outre le métier d'ingénieur (de bureau d'étude, de conception, etc.), des métiers d'expert techniques ont émergés. Ces deux familles de poste sont complémentaires. En substance: l'Ingénieur sait quoi faire, l'Expert comment faire.

Une autre famille de métiers est en cours d'émergence, celui d'architecte système. Son rôle est d'avoir une vision plus abstraite et holistique d'une famille de systèmes. Il participe à la définition du système, mais surtout aux réflexions stratégiques sur une famille de système : principes généraux, fonctions, liens entre celles-ci, mais également comment vérifier par la suite que le système remplira sa mission. Ce métier se distingue du rôle de Chef de Projet. Ainsi, l'Architecte dit quoi faire (techniquement), alors que le Chef de Projet qui distribue les rôles et assure la correcte réalisation du projet – dit qui fait quoi et quand.

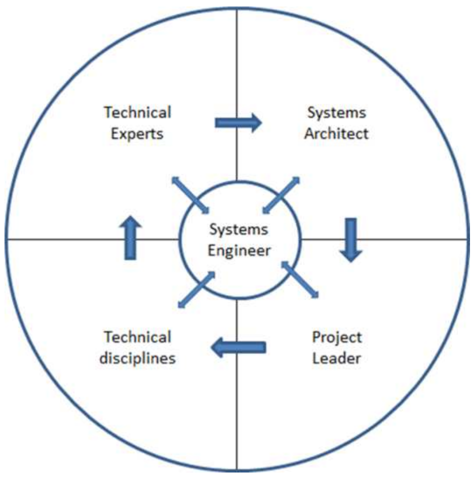

Figure 1 Liens entre les différents métiers

Le rôle d'un Architecte des Systèmes Aériens est de définir l'architecture d'un système avion complet, dans l'ensemble de ces dimensions techniques et industrielles. Il couvre l'ensemble des métiers du domaine aéronautique, et vise à définir les principes d'architecture du système dans sa globalité: réalisation, opération et maintenance.

1.2. ORGANISATION DU BENCHMARK

Pour le benchmark ingénierie système et architecture système, les travaux ont eu lieu dans la deuxième partie de 2018 et ont été effectué par le Junior Entreprise ISAE-SUPAERO à Toulouse. Dans l'ordre deux phases ont été identifiés :

1. identifier les formations en ingénierie systèmes proposées dans des écoles et universités de renom
2. évaluer la pertinence des formations proposées en ingénierie système à partir d'une grille de critères

Dans la phase 1, le choix a été de sélectionner 10 universités/écoles au sein de l'UE et 10 hors UE, et de cibles 10 formations initiales et 10 formations continues. Le choix a été retenu sur les 20 universités/écoles indiqués en figure 2.

Pays	Université / Ecole	Classement de Shanghai 2018 (Aerospace)	Type de formation	Nature du diplôme	Autre raison
Allemagne	TU Munich	32	Initiale (sur place)	Module du master Systems Engineering	
Allemagne	Universität Hamburg				
Australie	UNSW Australia (The University of New South Wales)	41	Continue (en ligne MOOC)	Certificat MOOC	MOOC
Belgique	Université catholique néerlandophone de Louvain (KUL)				
Espagne	Universidad Politecnica de Madrid	47			
Etats-Unis	MIT	13	Continue (en ligne)	Certificat professionnel	
Etats-Unis	Georgia Tech	2	Continue (en ligne + déplacement 3 fois à l'université)	Master professionnel en ingénierie système appliquée	Plusieurs choix
Etats-Unis	Georgia Tech	2	Continue (en ligne + déplacement 3 fois à l'université)	Certificat en ingénierie système	
Etats-Unis	Georgia Tech	2	Continue (en ligne + déplacement 3 fois à l'université)	Certificat en ingénierie système avancée	
Etats-Unis	University of Michigan Ann Arbor(UM)	3	Continue (sur place)	Master en ingénierie système + design	1 an offert INCOSE
Etats-Unis	Stanford University	19			
Etats-Unis	The University of California, Berkeley (UC Berkeley)				
France	Ecole polytechnique		Continue (sur place)	Certificat	
France	Centrale paris		Continue (sur place)	Master spécialisé en management de projet et ingénierie système	
Grande-Bretagne	Cranfield University		Continue ou initiale (sur place)	PgCert Systems Engineering for Defence Capability	Très flexible (11 mois à 4 ans
Grande-Bretagne	Cranfield University		Continue ou initiale (sur place)	PgDip Systems Engineering for Defence Capability	Très flexible
Grande-Bretagne	University of Southampton	28			
Hong Kong	The University of Hong Kong				
Italie	Sapienza University of Rome				
Japon	Keio University				
Pays-Bas	TU Delft	9			
Singapour	NUS				
Suède	KTH		Initiale (sur place)	Module du master ingénierie design Module du master design de produits intégrés	
Suisse	EPFL		Initiale (sur place)	Mineur du master Technologies spatiales	

Figure 2 Universités et Ecoles d'Ingénieurs retenus

Au final 20 instituts ont été audités, dans 12 pays différents, analysant 133 formations en systems engineering, dont 8 formations continues. Un certain nombre concerne des programmes entiers de formation (Master ou Master Spécialisé), d'autres concerne des modules dans des programmes « autre », par exemple un module ingénierie systèmes dans un Master Nuclear Engineering.

L'analyse a porté sur le contenu et si possible sur la façon d'enseigner et d'évaluer la connaissance, le but étant de voir si les programmes proposées à l'ISAE-SUPAERO proposent au moins ce que proposent les autres instituts, et d'apprendre de la façon que ces instituts font l'évaluation de la connaissance.

Des informations complémentaires ont été relevés, quant aux type de formation, la durée, une indication de prix si disponible, des prérequis, des travaux encadrés et des projets à faire dans le cadre de ces formations.

Le Junior Entreprise a remis les résultats sous forme d'un fichier Excel avec toutes les informations inclus, ce rapport en fait un extrait.

Remarque : Une fois dans l'analyse détaillé, on s'aperçoit que certaines de ces modules se trouvent plus sur le domaine des systèmes dynamiques et donc plus sur le domaine de l'automatique. Même si ces formations ont contribués à la compréhension de ce que les autres instituts proposent en termes de formation, ces modules ne sont pas détaillés dans ce rapport.

1.3. ORGANISATION DU RAPPORT

Ce rapport est organisé comme suit :

- Chapitre 2 liste les sujets qui remontent systématiquement dans les formations analysées, sujets qu'on estime donc important à couvrir dans les programmes de formation de l'ISAE-SUPAERO.
- Chapitre 3 fait une comparaison de haut niveau de ces sujets avec les différents programmes de formation de l'ISAE-SUPAERO et identifie les manques éventuelles.
- Chapitre 4 tire de conclusions de cette analyse.
- Chapitres 5 – 23 détaillent certaines formations analysées
    - Chapitre 5 – Ecole Polytechnique
    - Chapitre 6 – Ecole Centrale
    - Chapitre 7 – TU Delft
    - Chapitre 8 – Cranfield University
    - Chapitre 9 – University of Southampton
    - Chapitre 10 – TU München
    - Chapitre 11 – EPFL
    - Chapitre 12 – KTH
    - Chapitre 13 – KU Leuven
    - Chapitre 14 – MIT
    - Chapitre 15 – Georgia Tech
    - Chapitre 16 – Stanford University
    - Chapitre 17 – The University of California at Berkeley
    - Chapitre 18 – University of Michigan Ann Harbor
    - Chapitre 19 – The University of Hong Kong
    - Chapitre 20 – Keio University
    - Chapitre 21 – The University of New South Wales
    - Chapitre 22 – National University of Singapore
- Chapitre 23 est une copie de la partie « formation et enseignement » du contrat de la Chaire CASAC
- Chapitre 24 résume les activités du Junior Entreprise

2. ANALYSE DES RESULTATS

Les analyses montrent une compréhension relativement homogène du métier d'ingénieur systèmes. Les mots clés qui reviennent systématiquement sont :

Architecture

- Architecting
- Architecting design and evaluation
- Analyse critique d'architecture et des choix de conception
- Matrices structurelles de conception
- Choix de concepts
- Méthodes d'évaluation
- Theory and methods to identify, value and implement flexibility in design
- Trade-off and trade-off analysis
- Trade-off between conflicting demands of different disciplines by performing a detailed preliminary design
- Systems architecture
- Satisfaction de contraintes
- Pré-dimensionnent

Conception

- Conceptual design
- Reliability analysis
- Simulation of performance for scenarios
- Design definition and optimisation

Systems engineering

- Ingénierie des exigences
- Functions and requirements
- Frameworks and methods for ecosystem analysis and stakeholder analysis
- From concept to execution
- Analyse fonctionnelle
- Requirements definition
- Verification and validation
- V-model
- Systems engineering management
- Systèmes complexes
- Socio-technical systems

Decision analysis

- Decision and management of uncertainties
- Knowledge management
- Distinction entre produits, service et projets

Modelling

- Modélisation des systèmes
- Langages de modélisation et SysML
- Modélisation pour l'aide à la décision
- Modelling of distributed systems
- Models in verification

Project management

- Basics of decision making
- Cost modelling
- Risques de projet

Il convient donc d'analyser si les programmes de formation de l'ISAE-SUPAERO proposent ces sujets et sous quelle forme.

3. ANALYSE PAR RAPPORT AUX PROGRAMMES DE FORMATION DE L'ISAE-SUPAERO

3.1. PRISE EN COMPTE DANS LA FORMATION INGENIEUR ISAE-SUPAERO

Dans le programme de formation Ingénieur ISAE-SUPAERO, il faudra distinguer le tronc commun, les cours électifs en première et deuxième année, et les domaines/filières en dernière année.

Dans le tronc commun, qui s'étale sur les trois ans de formation, les sujets suivants sont abordés

Architecture

- Choix de concepts
- Systems architecture

Conception

- Conceptual design
- Design definition and optimisation

Systems engineering

- Ingénierie des exigences
- Functions and requirements
- From concept to execution
- Analyse fonctionnelle
- Requirements definition
- Verification and validation
- V-model
- Systems engineering management

Modelling

- Modélisation des systèmes

Project management

- Basics of decision making
- Cost modelling
- Risques de projet

De plus, les Projets Ingénierie et Entreprise (PIE) en troisième année visent à mettre en application toutes les connaissances acquises notamment dans le cadre des enseignements scientifiques et du tronc commun ingénierie et entreprise. Ces projets, dimensionnés pour un travail de groupe d'à peu près 5 à 6 étudiants, sont par nature multidisciplinaires, relèvent de l'ingénierie et non pas de pure recherche, et demandent aux élèves une autonomie très importante au niveau application des approches ingénierie systèmes et gestion de projet.

Dans le cadre de diverses cours électifs en première et deuxième année, les sujets suivant peuvent être appris :

Architecture

- Architecting
- Architecting design and evaluation
- Analyse critique d'architecture et des choix de conception
- Matrices structurelles de conception
- Choix de concepts
- Méthodes d'évaluation
- Theory and methods to identify, value and implement flexibility in design
- Trade-off and trade-off analysis
- Trade-off between conflicting demands of different disciplines by performing a detailed preliminary design
- Systems architecture
- Satisfaction de contraintes
- Pré-dimensionnent

Systems engineering

- Frameworks and methods for ecosystem analysis and stakeholder analysis
- From concept to execution
- Analyse fonctionnelle
- Requirements definition
- Verification and validation
- V-model
- Systems engineering management
- Systèmes complexes
- Socio-technical systems

Modelling

- Modélisation des systèmes
- Langages de modélisation et SysML
- Modélisation pour l'aide à la décision

Pour terminer, à travers des cours et travaux proposés par les domaines et filières en dernière année, les sujets suivants peuvent être appris :

Conception

- Conceptual design
- Reliability analysis
- Simulation of performance for scenarios
- Design definition and optimisation

Decision analysis

- Decision and management of uncertainties
- Distinction entre produits, service et projets

La conclusion est que le programme Ingénieur ISAE-SUPAERO couvre bien l'essentiel des sujets qui remontent des programmes proposés ailleurs. Le sujet de knowledge management n'en fait pas encore partie, mais il est prévu de l'inclure dans le cours électif architecture systèmes dès 2020. En revanche, tous les élèves ne voient pas la totalité des sujets, seulement les sujets listés pour le tronc commun sont vu par la totalité des élèves qui suivent les trois ans de formation à l'ISAE-SUPAERO.

3.2. PRISE EN COMPTE DANS LE MASTER OF AEROSPACE ENGINEERING

Le programme de formation Master of Aerospace Engineering consiste d'un tronc commun et de « majors » à choisir au cours de la première année. Ces majors permettent aux élèves de se spécialiser dans une voie spécifique. Le Master of Aerospace Engineering a un major Systems Engineering.

Dans le tronc commun du programme Master of Aerospace Engineering les sujets suivants sont proposés :

Conception

- Conceptual design
- Design definition and optimisation

Systems engineering

- Ingénierie des exigences
- Functions and requirements
- From concept to execution
- Analyse fonctionnelle
- Requirements definition
- V-model
- Systems engineering management

Modelling

- Modélisation des systèmes
- Langages de modélisation et SysML

Project management

- Basics of decision making
- Cost modelling
- Risques de projet

Dans le cadre du major Systems Engineering, les sujets suivants sont abordés :

Architecture

- Architecting
- Architecting design and evaluation
- Choix de concepts
- Méthodes d'évaluation
- Systems architecture

Conception

- Conceptual design
- Simulation of performance for scenarios

Systems engineering

- Ingénierie des exigences
- Functions and requirements
- Frameworks and methods for ecosystem analysis and stakeholder analysis
- From concept to execution
- Analyse fonctionnelle
- Requirements definition
- Verification and validation
- V-model
- Systems engineering management
- Systèmes complexes

Decision analysis

- Decision and management of uncertainties
- Distinction entre produits, service et projets

Modelling

- Modélisation des systèmes
- Langages de modélisation et SysML
- Modélisation pour l'aide à la décision
- Modelling of distributed systems
- Models in verification

La conclusion est que le programme Master of Aerospace Engineering ISAE-SUPAERO couvre bien l'essentiel des sujets qui remontent des programmes proposés ailleurs. Certains sujets manquent, mais le fait d'avoir un major systems engineering permet de se franchir de l'obstacle que la formation se fait sur deux ans (niveau M1 et M2) et non pas sur 3 ans (L3, M1, M2) comme avec le programme ingénieur ISAE-SUPAERO.

3.3. PRISE EN COMPTE DANS LE MASTERE SPECIALISEE SYSTEMS ENGINEERING

Le programme de la Mastère Spécialisée Systems Engineering se déroule sur un an et vise un public qui a déjà un diplôme de niveau M2. Les sujets couverts dans ce Mastère sont :

Architecture

- Architecting
- Architecting design and evaluation
- Analyse critique d'architecture et des choix de conception
- Matrices structurelles de conception
- Choix de concepts
- Méthodes d'évaluation
- Systems architecture
- Satisfaction de contraintes
- Pré-dimensionnent

Conception

- Conceptual design
- Reliability analysis
- Simulation of performance for scenarios
- Design definition and optimisation

Systems engineering

- Ingénierie des exigences
- Functions and requirements
- Frameworks and methods for ecosystem analysis and stakeholder analysis
- From concept to execution
- Analyse fonctionnelle
- Requirements definition
- Verification and validation
- V-model
- Systems engineering management
- Systèmes complexes
- Socio-technical systems

Modelling

- Modélisation des systèmes
- Langages de modélisation et SysML
- Modélisation pour l'aide à la décision
- Modelling of distributed systems
- Models in verification

Project management

- Basics of decision making
- Cost modelling
- Risques de projet

A travers un projet sur les premiers 6 mois, les différents sujets sont appliqués.
On note que le programme couvre bien les sujets demandés.

3.4. PRISE EN COMPTE DANS LE CERTIFICAT INGENIERIE SYSTEMES – INCOSE

Le certificat « INCOSE », accessible pour les élèves Ingénieur ISAE-SUPAERO, les élèves Master Aerospace Engineering – major Systems Engineering, et les élèves de la Mastère Spécialisée Systems Engineering vise à proposer à la fois un approfondissement des sujets ingénierie systèmes, et une préparation pour la certification ASEP/CSEP d'INCOSE. Pour cela, en particulier comme la certification est basé sur à 100% sur le « INCOSE Systems Engineering Handbook, Version 4, 2015 », les sujets suivants sont abordés, dans la limite de ce qu'enseigne le Handbook :

Architecture

- Architecting
- Architecting design and evaluation
- Matrices structurelles de conception
- Choix de concepts
- Méthodes d'évaluation
- Trade-off and trade-off analysis
- Systems architecture

Conception

- Conceptual design
- Reliability analysis

Systems engineering

- Ingénierie des exigences
- Functions and requirements
- Frameworks and methods for ecosystem analysis and stakeholder analysis
- From concept to execution
- Analyse fonctionnelle
- Requirements definition
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- Systems engineering management
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- Socio-technical systems

Modelling

- Modélisation des systèmes
- Modélisation pour l'aide à la décision
- Models in verification

Project management

- Basics of decision making
- Cost modelling
- Risques de projet

On note que quelques sujets qu'on peut qualifier comme spécialisation ne sont pas abordés dans le cadre de ce certificat. Les sujets autour de l'ingénierie systèmes « pur » sont tous adressés.

3.5. PRISE EN COMPTE DANS LES PROGRAMMES EUROSAE

EuroSAE propose divers programmes de formation, visant un public déjà en activité dans l'industrie. Ces programmes, en règle général des cours sur 3 à 10 jours, couvrent à chaque fois un sujet bien spécific. A noter que EuroSAE propose les cours suivants :

- Ingénierie des systèmes
- Réaliser un projet d'ingénierie système
- Ingénierie des exigences
- Introduction à l'ingénierie systèmes dirigée par les modèles (MBSE)
- Architecture et ingénierie des systèmes de systèmes

On retrouve bien les différents sujets identifiés.

3.6. IMPACT PAR RAPPORT AUX EXIGENCES INCOSE POUR CERTIFICATION D'UN PROGRAMME DE FORMATION

Depuis début 2019 il y a la possibilité de faire certifier le programme de formation par l'INCOSE, ce qui permet aux élèves de sortir directement avec le certificat ASEP/CSEP sans passer par un examen séparé. L'ISAE-SUPAERO va regarder en détail si de telle certification des programmes serait possible pour le programme Ingénieur ISAE-SUPAERO, le programme Master Aerospace Engineering – Major Systems Engineering, et pour la Mastère Spécialisée Systems Engineering. Les détails deviennent petit à petit disponibles et une analyse détaillée est prévue pour début 2020.

4. CONCLUSIONS

L'essentiel des besoins semble être couvert par les différentes formations proposées par l'ISAE-SUPAERO. Une voie intéressante serait d'investiguer plus en détail la certification par une partie des formations par l'INCOSE, plutôt que de faire certifier les candidats. Des possibilités pour améliorer l'offre des formations peuvent être discuté une fois l'analyse des attentes des industriels sera disponible.

5. ECOLE POLYTECHNIQUE / FRANCE

5.1. CERTIFICAT : FORMATION INGENIERIE DE SYSTEMES - CONCEPTION

5.1.1. KEYWORDS

- Fondamentaux de la conception et de l'Ingénierie de Systèmes
- Architecture et ingénierie des systèmes complexes
- Ingénierie du risque projet
- Ingénierie des exigences
- SysML pour modéliser efficacement un système industriel complexe

5.1.2. COURSE OUTLINE

- 5 programmes indépendants :
    - Fondamentaux de la conception et de l'Ingénierie de Systèmes :
        - Définition : système, ingénierie système, exigence
        - Cycle de vie, analyse fonctionnelle
        - Brève introduction à l'ingénierie dirigée par les modèles (MBSE).
        - Cas d'étude : Analyse du retour d'expérience du programme Apollo
    - Ingénierie des exigences :
        - Fondamentaux de l'ingénierie des exigences aux travers d'exercices et d'exemples
        - Voice of Customer, Kano, GORE
        - Langage naturelle, modélisation conceptuelle
        - Matrice QFD, outillage des exigences
        - Examen "Blanc" de la Certification IREB
    - Architecture et ingénierie des systèmes complexes :
        - Fondamentaux de l'approche système au travers d'un exemple
        - Les éléments clé d'une ingénierie système (pour la conception architecturale)
        - Les grands principes de la conception architecturale (architecting)
        - La démarche de conception architecturale
    - Ingénierie du risque projet :
        - Mesurer les gains attendus de la maîtrise des risques dans les projets
        - Se repérer dans l'approche de maîtrise des risques
        - Identifier, évaluer les risques
        - Traiter les risques, déployer le plan de management des risques
        - Utiliser le retour d'expérience en vue d'une meilleure maîtrise des risques
    - SysML pour modéliser efficacement un système industriel complexe :
        - Etude de cas fil conducteur (33% de TP)
        - Introduction au SysMl
        - La modélisation des exigences
        - La modélisation structurelle
        - La modélisation dynamique
        - La modélisation transverse"

5.2. MODELING AND ANALYSIS OF CYBER - PHYSICAL SYSTEMS

5.2.1. KEYWORDS

- Introduction aux systèmes cyber-physiques, modèles synchrones
- Modélisation et simulation de systèmes hybrides
- Conception des Systèmes Informatiques

5.2.2. COURSE OUTLINE

- L'interaction de composantes informatiques, qui calculent et communiquent, avec leur environnement régi par des lois physiques, comme pour un avion ou un système médical implanté, est au centre du domaine émergent des systèmes cyber-physiques. Les systèmes embarqués en sont naturellement une brique de base. Mais alors que dans les systèmes embarqués traditionnels se concentrent essentiellement sur les aspects informatiques, ce cours propose de s'attacher plus particulièrement à l'interface entre le monde discret informatique et le monde physique continu. Maitriser la modélisation, l'analyse et le contrôle du comportement de tels systèmes est crucial pour permettre dans le futur d'améliorer l'efficacité, les fonctionnalités, et d'assurer la fiabilité de ces systèmes, toujours plus complexes et souvent critiques en terme de sécurité ou de coût.
- Le cours s'attachera à trouver un équilibre entre modélisation et vérification, et entre fondations théoriques et les aspects pratiques. Il introduira notamment aux principes et à l'utilisation de quelques outils représentatifs de l'état de l'art, et s'intéressera à des cas d'étude réalistes (tels qu'un modèle temporel de pacemaker modélisé et vérifié avec l'outil Uppaal).
- Le cours est central aux thématiques de la filière Conception des Systèmes Informatiques, mais il est également naturel dans le parcours Electrical Engineering ou dans la filière Algorithmes et Fondements des Langages de Programmation. Des sujets de projets 3A en lien avec des thématiques peuvent être proposés.
- Introduction aux systèmes cyber-physiques, modèles synchrones
- Langages synchrones: spécification et éléments de vérification
- Modélisation par automates temporisés
- Logique temporelle et verification par model-checking
- Modélisation et simulation de systèmes hybrides
- Analyse d'atteignabilité de systèmes différentiels et hybrides
- Modélisation (fin), stabilité et contrôle de systèmes hybrides
- Analyse logique des systèmes hybrides

6. ECOLE CENTRALE / FRANCE

6.1. MASTERE SPECIALISE EN MANAGEMENT DE PROJET ET INGENIERIE SYSTEME

6.1.1. KEYWORDS

- Principes de conduite d'un projet au sein d'une entreprise
- Savoir conduire la définition et le développement d'un produit (matériels et logiciels) en intégrant les contraintes du soutien logistique et de l'industrialisation
- Assurance qualité produit/FMDSTE

6.1.2. COURSE OUTLINE

- 5 modules (détails plus bas)
  - Principes de conduite d'un projet au sein d'une entreprise
  - Principes généraux de l'ingénierie système-Savoir conduire la définition et le développement d'un produit (matériels et logiciels) en intégrant les contraintes du soutien logistique et de l'industrialisation.
  - Assurance qualité produit/FMDSTE
  - Stratégie d'entreprise et marketing produits et services
  - Réponse a un appel d'offres international-Construire, rédiger et présenter une offre en réponse à une consultation publique ou privée, nationale ou internationale.
- 3 spécialités au choix (détails plus bas)
  - Spécialité Ingénierie des Produits : référentiel de management, maîtrise des risques projets, ingénierie des produits, système et architecture orientée services
  - Spécialité Ingénierie du Soutien et des Services : éléments de soutien et systèmes de soutien, ingénierie, logistique, quantification du soutien, maintien en condition opérationnelle et services, management du soutien et des services
  - Spécialité Systèmes embarqués - Objets connectés : - Sûreté de fonctionnement et sécurité logicielle et marétielle - Electronique embarquée - Logiciel embarqué
- Module 1: Principes de conduite d’un projet au sein d’une entreprise
  - Capable de structurer et piloter un projet couvrant une ou plusieurs phases du cycle de vie d’un système ou équipement en s’appuyant sur toutes les fonctions de l’entreprise.
- Module 2 : Principes généraux de l’ingénierie système (matériels et logiciels)
  - Capable de conduire la définition et le développement d’un produit (matériels & logiciels) en intégrant les contraintes du soutien et de l’industrialisation.
- Module 3 : Assurance qualité produit /FMDSTE
  - Capables de gérer les performances de sûreté de fonctionnement, de sécurité et de sûreté et plus globalement sauront conduire une démarche de maîtrise de tout type de performance.
- Module 4 : Stratégie d’entreprise et marketing produits & services
  - Capables d'établir une stratégie d’entreprise dans les domaines des produits et des services, à l’international, en intégrant les composantes industrielles fondamentales des marchés, de l’investissement, du financement, du business development.
- Module 5 : Réponse à un appel d’offres international - contractualisation
  - Capables de construire, rédiger et présenter une offre en réponse à une consultation publique ou privée, nationale ou internationale.
- Spécialité 1 : Spécialité Ingénierie des Produits : -- Référentiel de management -- Revue et maîtrise des projets -- Ingénierie des produits -- Système et architecture orientée services

- Spécialité 2 : Ingénierie du Soutien et des services : -- Eléments de soutien et systèmes de soutien - l'ingéinierie logistique - la quantification du soutien - Maintien en condition opérationnelle et services - Management du soutien et des services
- Spécialité 3 : Spécialité Architecte de Systèmes Embarqués : -- Ingénierie des systèmes embarqués -- Sûreté de fonctionnement et sécurité logicielle et marétielle -- Electronique embarquée -- Logiciel embarqué

6.2. INTRODUCTION TO COMPLEX SYSTEM ANALYSIS

6.2.1. KEYWORDS

- Foundations for the analysis of modern complex systems
- framework for analysing, managing and controlling modern complex engineering systems

6.2.2. COURSE OUTLINE

- Objectives:
  - Methodological: to learn the framework for analysing, managing and controlling modern complex engineering systems;
  - Practical: to understand which modelling and analysis paradigms are more suitable to different problems, taking into account their strengths and weaknesses in dependence of the particular situation addressed (in terms of complexity, uncertainty, knowledge and information). The course presents the foundations for the analysis of modern complex systems. The aim is to provide the students with the adequate tools for handling with scientific rigor the complexities and uncertainties associated to the problem. The expertise offered is part of the background knowledge of many diverse professional jobs such as system engineer, process engineer, project manager, process manager, risk manager…
- Content:
  - A system is a group of interacting elements (or subsystems) having an internal structure which links them into a unified whole. A complex system is made by many components interacting in a network structure. Most often, the components are physically and functionally heterogeneous, and organized in a hierarchy of subsystems that contributes to the system function. This leads to both structural and dynamic complexity. Structural complexity derives from 1) heterogeneity of components across different technological domains due to increased integration among systems, and 2) scale and dimensionality of connectivity through a large number of components (nodes) highly interconnected by dependences and interdependences Dynamic complexity manifests through the emergence of (even unexpected) system behavior in response to changes in the environmental and operational conditions of its components.
  - The analysis of these systems cannot be carried out only with classical methods of system decomposition and logic analysis; a framework is needed to integrate a number of methods capable of viewing the problem from different perspectives (topological and functional, static and dynamic, etc.), under the existing uncertainties. Then, in particular the following methods of analysis will be considered:
    - Structural/topological methods based on system analysis, graph theory, etc.; these methods are capable of describing the connectivity of a complex system and analyzing its effects on the system functionality, on the cascade propagation of afailure and on its recovery (resilience), as well as identifying the elements of the system which must be most robustly controlled because of their central role in the system connectivity.
    - Logical methods based on system analysis, hierarchical logic trees, etc.; these methods are capable of capturing the logic of the functioning/dysfunctioning of a complex system, and of identifying

the combinations of failures of elements (hardware, software and human) which lead to the loss of the system function.

- Phenomenological/Functional methods, based on transfer functions, state dynamic modeling, input-output modeling and control theory, agent-based modeling etc.; these methods are capable of capturing the dynamics of interrelated operation between elements (hardware, software and human) of a complex system and with the environment, from which the dynamic operation of the system itself emerges.

- Flow methods, based on detailed, mechanistic models (and computer codes) of the processes occurring in the system; these methods are capable of describing the physics of system operation, its monitoring and control.

6.3. CONCEPTION DES SYSTEMES COMPLEXES

6.3.1. KEYWORDS

- Conception de l'architecture système en utilisant SySML
- Introduction à la conception des systèmes complexes
- Introduction à l'aide à la décision dans la conception des systèmes complexes

6.3.2. COURSE OUTLINE

- Le but de ce cours est de développer une base forte des méthodes et outils des systèmes complexes qui permets aux étudiants de participer avec succès dans e projets de développement de nouveau produits et services tels que conception d'un avion, de véhicule, satellite, des systèmes de trafiques aériennes et autres, etc. Le contenu du cours est le suivant :
  - Introduction à la conception des systèmes complexes
  - Introduction au processus de conception et la différence avec les autres processus de conception (produit et services)
  - Introduction aux méthodes de maîtrise de la complexité
  - Introduction à l'aide à la décision dans la conception des systèmes complexes
  - Conception de l'architecture système en utilisant SySML

6.4. INGENIERIE DE SYSTEMES COMPLEXES

6.4.1. KEYWORDS

- Problèmes de satisfaction de contraintes
- Méthode des matrices structurelles de conception
- Modélisation à l'aide de graphes
- Modélisation à l'aide d'automates d'états finis
- Dimensionnement du moteur et de ses accessoires

6.4.2. COURSE OUTLINE

- L'objectif du cours est de familiariser les élèves avec un éventail de techniques, principes et formalisme de modélisation de systèmes complexes, ainsi que de montrer les possibilités mais aussi les limites de la modélisation de systèmes complexes.
- Compétences acquises en fin de cours : A l'issu du cours, les élèves auront acquis un savoir théorique et des savoirs faire pratiques sur la science des modèles et l'ingénierie de la modélisation.

- Le cours abordera les sujets suivants :
    - modélisation des processus métiers ;
    - méthode des matrices structurelles de conception ;
    - architecture système ;
    - modélisation à l’aide de graphes ;
    - modélisation à l’aide d’automates d’états finis ;
    - problèmes de satisfaction de contraintes ;
    - raisonnement sur l’incertain ;
    - langages ;
    - limites de la calculabilité.

6.5. MODELISATION POUR L'AIDE A LA DECISION

6.5.1. KEYWORDS

- Data Enveloppement Analysis.
- Décision en présence de risque, décision dans l'incertain, théorie de l'utilité, arbres de décision
- Présentation de modélisations de problèmes de décision utilisant divers cadres de modélisation (graphes, programmation linéaire, etc.)

6.5.2. COURSE OUTLINE

- Objectifs
    - La prise de décision est une activité intrinsèque au métier d'ingénieur/manager. Plus que jamais dans une économie mondialisée, complexe, et pleine d'imprévus, l'entreprise se trouve dans l'obligation de prendre des décisions stratégiques, tactiques et opérationnelles lourdes de conséquences (financières, humaines, etc.) pour sa compétitivité. Pour appréhender les problèmes de décision complexes auxquels ils seront confrontés les ingénieurs et managers de demain doivent disposer des concepts et méthodes permettant de formaliser un problème de décision. Le cours vise à introduire un certain nombre de modèles classiques permettant de représenter et résoudre des problèmes de décision dans différents contextes (décision dans l'incertain, décision multicritère, etc.).
- Compétences acquises en fin de cours
    - Ce cours vise à présenter des modélisations de différents problèmes concrets de décision. Il s’agit de développer les aptitudes des étudiants à élaborer et mettre en œuvre des modèles pertinents face à une situation de décision.
    - À l'issue du cours, l'élève maîtrisera quelques méthodes/modélisation d'aide à la décision. Il saura les utiliser de façon opérationnelle dans le cadre de problèmes d'entreprises. Il aura aussi les éléments nécessaires pour prendre du recul et avoir un sens critique par rapport à ces méthodes, et ainsi en distinguer leurs performances et leurs limites d’application.
- Contenu
    - Introduction à l'activité d'aide à la décision, concepts de base.
    - Décision en présence de risque, décision dans l'incertain, théorie de l'utilité, arbres de décision
    - Décision multicritère et modélisation des préférences, introduction à quelques modèles d'agrégation simples.
    - Présentation de modélisations de problèmes de décision utilisant divers cadres de modélisation (graphes, programmation linéaire, etc.). Présentation d'outils de modélisation et de résolution (modeleurs et solveurs).
    - Data Envelopment Analysis.

7. TU DELFT / PAYS-BAS

7.1. MASTER AEROSPACE ENGINEERING

7.1.1. COURSE OUTLINE

- Course AE4S12E: Exercise Space Systems Engineering (p92 of the brochure)
- The course aims to enable students to further develop their systems engineering skills with hands-on experience. There are three high-level learning objectives:
  - 1. Participants shall be able to analyze the project from a SE perspective including e.g. its requirements, constraints, and process.
  - 2. Based on the analysis in 1, participants shall be able to generate a set of concepts by synthesizing elements from both SE (especially concurrent engineering) and spacecraft engineering aspects.
  - 3. Participants shall be able to evaluate different concepts produced by themselves or by others, in terms of well-justified criteria.

7.2. INTRODUCTION TO DESIGN IN COMPLEX SYSTEMS

7.2.1. COURSE OUTLINE

- Hands-on learning during 5 consecutive days of project work. Students take part in a week-long programme of (guest) lectures, workshops, and project work in teams. Daily assignments are graded. The final product is a synthesis of these assignments and to bepresented on the 4th day. These products are reviewed by a professional expert and instructors.

7.3. OTHER COURSES

TU Delft has several other courses that somehow were not included in the investigation. They will be included in an updated version of this report in 2020.

8. CRANFIELD UNIVERSITY / ROYAUME-UNI

8.1. MSc/PgCert/PgDip Systems Engineering for Defence Capability

Three programs with a very similar set-up.

8.1.1. Keywords

- Availability, Reliability, Maintainability and Support, Strategy
- Systems Approach to Engineering
- Decision Analysis, Modelling and Support
- Advanced Systems Engineering Workshop

8.1.2. Course outline

- 7 Compulsory modules / 10 Elective modules
- Compulsory Modules
  - Systems Approach to Engineering
  - Lifecycle Processes Introduction
  - Lifecycle processes Advanced
  - Capability Context
  - Applied Systems Thinking
  - Advanced Systems Engineering Workshop
  - Thesis
- Elective Modules
  - Modules to the value of 50 credits selected from:
  - Availability, Reliability, Maintainability and Support, Strategy
  - Decision Analysis, Modelling and Support
  - Human Factors Integration
  - Introduction to Defence Capability
  - Model Based Systems Engineering
  - Networked and Distributed Simulation
  - Systems of Systems Engineering
  - Simulation and Synthetic Environments
  - Systems Engineering Workshop

8.2. Aerospace System Development and Life Cycle Model

8.2.1. Keywords

- System Integration, Verification and Validation

8.2.2. Course outline

- Aim
  - To introduce the student to system engineering concepts, system lifecycle models and system design processes and methods.

- Syllabus
  - Introduction to Systems

- Life Cycle Models
- System Requirements
- Systems Design
- System Integration, Verification and Validation

- Intended learning outcomes – on successful completion of this module a student should be able to:
  - Demonstrate a understanding of the basic concepts of the main life-cycle models.
  - Discuss the advantages and disadvantages of these models.
  - Define and analyse system requirements and specifications.
  - Determine system development process and define the work to be performed at different development phases.
  - Apply development life-cycle models to the AVD Group project.

8.3. SPACE SYSTEM ENGINEERING

8.3.1. KEYWORDS

- System design methodology: trade-off analysis, design specifications, system budgets.
- Spacecraft sub-systems design

8.3.2. COURSE OUTLINE

- Aim
  - To demonstrate how to develop the design of a space system, from the initial mission objective, through requirements definition, concept development and trade-off, and through to a baseline design.
- Syllabus
  - Brief history & context: Background to the development of space, agencies, funding, future missions.
  - Introduction to space system design methodology: requirements, trade-off analysis, design specifications, system budgets.
  - Spacecraft sub-systems design: Structure & configuration; Power, the power budget and solar array and battery sizing; Communications and the link budget; Attitude determination and control; Orbit determination and control; Thermal control.
  - Mission and payload types Spacecraft configuration: examples of configuration of spacecraft designed for various mission types; case study.
  - Introduction to cost engineering.
  - Space and Spacecraft Environment: Radiation, vacuum, debris, spacecraft charging, material behaviour and outgassing.
  - Assembly, Integration and Test processes; Launch campaign; Space mission operations.
- Intended learning outcomes – on successful completion of this module a student should be able to:
  - Establish quantitative mission requirements.
  - Characterise the mission design drivers and identify solution options at system and subsystem level.
  - Evaluate the performance of options by means of a trade-off analysis.
  - Produce a baseline system definition, with appropriate engineering budgets.
  - Outline a programme plan to verify the system performance."

9. UNIVERSITY OF SOUTHAMPTON / ROYAUME-UNI

9.1. CONCURRENT ENGINEERING DESIGN

9.1.1. KEYWORDS

- computer simulations
- Data management tools
- Spacecraft design

9.1.2. COURSE OUTLINE

- Module Aims: To undertake an industrially relevant spacecraft design exercise using principles studied in the Space Systems Engineering 2 module, enabling you to apply knowledge and understanding in a functional manner.
- Having successfully completed the module, you will be able to apply project management and systems engineering skills to a real-world spacecraft design, taking into account relevant standards and regulations (including those focusing on environmental impacts). You will be able to understand the different roles and responsibilities of team members in spacecraft design projects, recognise the need for data management tools and use these for enabling concurrent design practices, understand the role of computer simulations in the spacecraft design process and apply these tools to spacecraft design problems, and communicate your work in written form and verbally.
- Having successfully completed this module, you will be able to demonstrate knowledge and understanding of:
  - How to use good management practices for space projects
  - How different roles contribute to spacecraft design projects
  - How data management and simulation tools can be used to support spacecraft design
- Having successfully completed this module you will be able to:
  - Critically analyse alternative spacecraft design configurations and options
  - Identify and apply appropriate data management and design software solutions to spacecraft design
  - Design space missions using a concurrent design approach
  - Transferable and Generic Skills
- Having successfully completed this module you will be able to:
  - Work as part of a team
  - Collate and prioritise information according to design objectives
  - Solve problems systematically and concurrently
  - Communicate design choices and justifications using written and verbal methods"

9.2. SPACE SYSTEM ENGINEERING

9.2.1. KEYWORDS

- Spacecraft design
- Concurrent design

9.2.2. COURSE OUTLINE

- Module Overview: This module will provide an understanding of the processes and methods used in industry to design spacecraft. By taking a systems engineering approach, it will fit with other modules that are taking a detailed look at spacecraft subsystems, whilst emphasising the concurrent and iterative nature of spacecraft design, beginning from the definition of a space mission and the identification of a suitable payload to the final assembly, integration and verification. Students will be introduced to systems engineering, concurrent design, spacecraft design optimisation techniques, standards, and regulatory issues. In addition, seminars that discuss real space missions will demonstrate how these methods have been applied in industry. Finally, students will carry out a limited group project to put the key concepts and methods into practice.

- Module Aims: Having successfully completed the module, you will be able to understand where spacecraft design drivers come from and be able to apply concepts of space systems engineering to the design of a spacecraft. You will also gain an understanding of the design lifecycle, the design approaches that are used in industry, how these are tailored to specific missions, how to perform trade-offs in a quantitative manner, how compliance with standards and regulations will impact the design, and how the design is verified. These skills will be highlighted in seminars (some from external speakers) that will provide examples from real space missions. Finally, you will put these concepts into practice in a small group design project that will provide you with the skills needed to approach more complicated space systems design projects.
  - Having successfully completed this module, you will be able to demonstrate knowledge and understanding of:
  - Where spacecraft design drivers come from
  - How lifecycles are used to manage space projects
  - What methods can be used to produce optimal spacecraft designs
  - What impacts standards and regulations have on spacecraft design
  - How spacecraft design is verified
- Having successfully completed this module you will be able to:
  - Apply space project management and design methods to spacecraft design challenges
  - Incorporate standards and regulations into spacecraft design
  - Identify information requirements and sources for spacecraft design
  - Critically evaluate design options
  - Develop appropriate test procedures to verify spacecraft designs
  - Transferable and Generic Skills
- Having successfully completed this module you will be able to:
- Study and learn independently and as part of a team
  - Solve problems systematically
  - Adopt appropriate methodologies and practices for design
  - Communicate design choices and justifications using written and verbal methods"

10. TU MUNICH/ ALLEMAGNE

10.1. SYSTEMS ENGINEERING: MODULE DU MASTER SYSTEMS ENGINEERING

10.1.1. KEYWORDS

- Model-based simulation
- Model-based design
- Mathematical modelling
- System definition

10.1.2. COURSE OUTLINE

- System Definitions
- Mathematical and Conceptual Basics
- Modelling and Simulation of Systems
- System Optimization by Linear and Dynamic Programming
- Evaluation Methods, Basics of Decision Making
- System Engineering Management
- Methods for the planning, controlling and conducting of projects with regard to technology, time and costs

10.2. SYSTEMS ENGINEERING: MODULE DU MASTER AEROSPACE ENGINEERING

10.2.1. KEYWORDS

- Model-based simulation
- Model-based design
- Mathematical modelling
- System definition

10.2.2. COURSE OUTLINE

- System Definitions
- Mathematical and Conceptual Basics
- Modelling and Simulation of Systems
- System Optimization by Linear and Dynamic Programming
- Evaluation Methods
- Basics of Decision Making
- System Engineering Management
- Methods for the planning, controlling and conducting of projects with regard to technology, time and costs

10.3. SOFTWARE ARCHITECTURE: MODULE DU MASTER AUTOMOTIVE SOFTWARE ENGINEERING

10.3.1. KEYWORDS

- Software architecture
- Model-driven software development

10.3.2. COURSE OUTLINE

- At the end of the module participants understand the importance of software architecture for the successful outcome of software development projects. They know how to apply techniques for the description, construction, reuse and evolution of a software architecture. They understand architectures which are used for the construction of systems of systems as well as modern trends like modelling software architectures as part of a model-driven development approach. They understand the importance of software architecture for software reuse.
- Description of Software Architectures
- Construction of Software Architectures
- Reuse of Software Architectures
- Evolution of Software Architectures and Refactoring
- Architectures for Systems of Systems
- Model-Driven Software Development
- Current Trends

10.4. MODELLING AND VERIFICATION OF EMBEDDED SYSTEMS

10.4.1. KEYWORDS

- Embedded systems modelling

10.4.2. COURSE OUTLINE

- Basic principles of programming embedded systems design.
- At the end of the module, students will be able to understand and apply the theoretical basics of embedded systems modeling, verification, and synthesis. They will have a good understanding of concepts behind formal verification, model checking and synthesis tools and will be able to use such tools for verification and synthesis problems arising in the industry.
- This course will discuss formal modeling, verification, and synthesis of embedded systems (a.k.a hybrid systems). These systems consist of both continuous and discrete dynamics, providing a rigorous modeling framework for many safety-critical applications including automotive, aerospace, transportation systems, chemical process, critical infrastructure, energy, robotics, healthcare, etc. A large part of this course will be on formal verification of embedded systems against complex logic specifications and a few lectures at the end on formal synthesis. Examples of such logic specifications include linear temporal logic (LTL) or automata on infinite strings.

10.5. MODEL CHECKING

10.5.1. KEYWORDS

- Model checking
- Hardware and software models

10.5.2. COURSE OUTLINE

- Successful participation enables students to
  - explain the role of model checking for ensuring hardware and software quality
  - give formal models of simple hardware and software systems
  - write formal specifications of simple safety and liveness properties using temporal logic

    - explain algorithms for checking if a program satisfies a given specification and apply them to small examples
    - understand and explain techniques for palliating the state-explosion problem
- The course teaches the fundamentals of Model Chekcing. Topics include:
    - Representation of hardware and software systems using formal models of computations, e.g., transition systems, pushdown systems, Kripke structures, finite and infinite state automata.
    - Representation of specifications using formal logics and automata, e.g., linear and branching time temporal logics, automata on finite and infinite.
    - Decidability and complexity of various classes of formal models and specifications, e.g., complexity of finite state model checking for linear and branching time logics.
    - Techniques for palliating the state-explosion problem e.g., binary decision diagrams, partial-order reduction, abstraction.
    - Industrial application of model checking, e.g., discovery of concurrency bugs, verification of systems software.
    - Practical experience in applying model checking tools, e.g., Spin, Blast, CBMC.

10.6. MODELLING OF DISTRIBUTED SYSTEMS

10.6.1. KEYWORDS

- Systems components
- Formal specification
- Systems as state machines

10.6.2. COURSE OUTLINE

- At the end of the module students know the essential fundamental terms of specification, modular design, abstraction, refinement, and verification of concurrent, distributed interactive systems. They have a deep understanding of the modelling and consequently learn how to deal with many aspects of the distributed systems, their behaviour and communication in the methodological way. They obtain methods competence of the existing techniques for modelling and formal specification and systems development.
- Almost all current computer and software systems run in any form as networks. Additionally they are not only networked among themselves, in fact they are connected with physical and technical processes and according to this they use various interfaces. Thus, for studying modern software systems and their systematic development, topics such as concurrency, interaction and co-ordination of systems are central and important to know and understand. Modelling and systematic working with such systems deals with a lot of various questions, phenomena and difficulties, in contrast to sequential, not-interactive systems. This lecture presents fundamental concepts and models for distributed systems as well as description techniques to describe and specify their structure and properties with the goal to analyse and finally to verify their characteristics. The lecture covers specific questions and approaches to find models of distributed systems, their theories, structures and connections.
- Concurrent, distributed, cooperating systems: Fundamental ideas and substantial characteristics
- Systems as state machines
- Functional description of system components
- Structure and distribution
- Processes as execution traces in distributed systems
- Refinement of systems
- Message-synchronous systems

11. EPFL / SUISSE

11.1. MINOR OF SPACECRAFT DESIGN AND SYSTEM ENGINEERING

11.1.1. KEYWORDS

- Managing risks and uncertainty
- Management of Systems Development Projects

11.1.2. COURSE OUTLINE

- Introduction and basic concepts
- Management of Systems Development Projects
- Project planning (part 1)
- Estimating costs and time
- Project planning (part 2): Design & construction
- Project planning (part 3): Test & evaluation
- Scheduling for successful projects
- Student presentations
- Quality & quality assurance
- Organising projects
- Managing risks and uncertainty
- Change and avoidance of project failure
- Summary and conclusions

11.2. OTHER COURSES

EPFL has other courses that somehow did not get into this benchmark. They will appear in an updated version of this report in 2020.

12. KTH / SUÈDE

12.1. BUILDING INFORMATION MODELLING FOR PROJECT MANAGEMENT

12.1.1. KEYWORDS

- functions and requirements
- Conceptual design
- Socio-technical systems

12.1.2. COURSE OUTLINE

- This is an intensive, structured one-week programme that introduces the learning goals of the the Fundamentals Line in the context of the SEPAM MSc programme. In this week, students start with learning how to design in socio-technical systems.
- Each day, they attend lectures and work on group assignments that are related to a real-world design problem. In this way, students learn to use the basic vocabulary, concepts, analytical and design methods for the designing of technical structures, institutions and stakeholder processes. This body of knowledge will be elaborated upon in the subsequent courses of the Fundamentals Line.
- This course requires full attendance during all scheduled hours. Students work in teams and under supervision.
- Study Goals After completion of the course, the student is able to:
  - a) Explain what socio-technical systems are and what designing in a socio-technical system entails;
  - b) Use concepts such as structure, process, context and driver in relation to systems design and the system life cycle;
  - c) Apply basic techniques for conceptual design, especially identifying and formulating objectives, functions and requirements, generating alternatives and evaluating alternatives;
  - d) Explain what an institution is, what institutional design entails, and how the desiging of institutions differs from designing; technical structures;
  - e) Can contrast positivist and constructivist approaches to designing in a multi-actor system;
  - f) Can reflect on the complexity of the case that was used to practice designing

12.2. COMPUTER SYSTEMS ARCHITECTURE

12.2.1. KEYWORDS

- analyze a problem situation in complex, technological, large-scale systems in multi-actor environments

- decision, project and risk management
- suitable design approach for specific design challenges

12.2.2. COURSE OUTLINE

- The course introduces design thinking in socio-technical systems as the core orientation of the entire SEPAM master. Students learn about designing complex technological systems in multi-actor environments. It follows a storyline from understanding socio-technical systems towards creating artefacts to realize change in socio-technical systems. Different perspectives on systems design are discussed to provide students with a background for working with designers from different disciplines. Thereby, the course lays the foundation for further design-oriented courses. Typical questions the module will address are:

- How to explore a problem situation?
- How to oversee a design challenge?
- How to formulate a design task?
- What is a suitable design approach for specific design challenges?

- Study Goals After completion of the course, the student is able to
  - use and differentiate discuss concepts and terminology related to the design in socio-technical systems
  - analyze a problem situation in complex, technological, large-scale systems in multi-actor environments
  - use and combine methods and tools for requirements analysis and conceptual design
  - use and compare methods and tools that facilitate systems design and engineering
  - apply and compare methods and tools related to decision, project and risk management
  - determine a suitable design approach for specific socio-technical design challenges
  - use and combine methods anc and modelling to address complexity and uncertainty in design processes

12.3. DEGREE PROJECT IN SYSTEMS ENGINEERING, SECOND CYCLE

12.3.1. COURSE OUTLINE

- Core modules:
  - Systems architecture
  - Systems engineering
  - Knowledge management
  - Systems engineering project management
  - Systems approch to project management
- Systems Methodology and Management (at least 2):
  - Model-Based Systems Engineering
  - Management of Technological Innovation
  - Analyzing Hi-Tech Opportunities
  - Engineering Business Finance Fundamentals
  - Cost Analysis & Engineering Economy
  - Engineering Economics and Project Evaluation
  - Marketing of Hi-Technology Products and Innovations
  - Research in Technology & Innovation Management
  - Management & Organization (2MCs)
  - Applied Forecasting Methods
  - Decision Analysis
  - Large Scale Systems Engineering
  - Topics in Systems Engineering
  - Applied Policy Analysis
- Systems Application (at least 2):
  - SDM Research Project
  - Management of Industrial R&D
  - Creativity and Innovation
  - Strategic & New Product Development #
  - New Product Management #
  - Business Models for Hi-Tech Products
  - Managing Operations (2 MCs)
  - Global Infrastructure Project Management
  - Project Engineering
  - Advanced Power Systems Analysis

    - Sludge & Solid Waste Management
- Energy Engineering
    - Manufacturing Systems Engineering
    - Transportation Management & Policy
    - Intermodal Transportation Operations

12.4. APPLIED SYSTEMS ENGINEERING

12.4.1. KEYWORDS

- Applied Systems Engineering

12.4.2. COURSE OUTLINE

- This modules present ideas of systems analysis and project management in a manner which demonstrates their essential unity. It uses the systems development cycle as framework to discuss management of engineering and business projects from conception to termination. The module is divided into three interrelated parts: systems analysis and project management, project selection and organization behaviour, and systems and procedures in project planning and control.

13. KU LEUVEN / BELGIQUE

13.1. DESIGN OF SOFTWARE SYSTEMS: MODULE OF MASTER OF ENGINEERING, COMPUTER SCIENCE

13.1.1. KEYWORDS

- aspects of software designs with respect to analysis and requirements, design, implementation and organizational impact
- Design decisions for software systems
- analyzing the quality of an existing design

13.1.2. COURSE OUTLINE

- At the end of this course, the student will be able to take and motivate well-founded design decisions for software systems. This entails being able to propose multiple relevant software designs for a given problem, to compare the positive and negative aspects of software designs with respect to analysis and requirements, design, implementation and organizational impact, and to take and motivate a well-founded design decision. The theoretical aspects of the course are applied in a group project where a non-trivial, existing (but new to the students) application is extended with new functionality. The objectives of this group project are:
  - analyzing the quality of an existing design.
  - deciding what parts of an existing system need to be changed to allow for new functionality
  - designing software for new functionality without breaking the existing software system.
  - writing reports that clearly convey the proposed changes and design decisions.
- The following topics are addressed in the colleges:
  - Overview of software development processes (waterfall model, spiral model, iterative development, agile development).
  - Object-oriented analysis and design using the UML modeling language.
  - Study, evaluation and usage of GRASP patterns.
  - Study, evaluation and usage of design patterns.
  - Implementation techniques for realizing high quality object-oriented implementations (unit testing, refactoring, profiling).
  - Techniques for assessing the quality of the design and implementation of existing software systems.

13.2. MODELLING OF COMPLEX SYSTEMS

13.2.1. KEYWORDS

- What is modelling
- Modelling of dynamic systems

13.2.2. COURSE OUTLINE

- The content of this course is originally based on the book Logic in Computer Science by Michael Huth and Mark Ryan, and was extended with additional materials, e.g., about modelling and problem solving using predicate logic, techniques from knowledge representation and articificial intelligence, and specification and verification in Event-B, CTL and LTL with abstraction and refinement. The book contains many exercises. The auteurs have a website with for each chapter a number of multiple choice questions with feedback for each choosen answer. The book deals with certain topics in deeper way than is intended. In particular, the chapters on modal logic and OBDD's can be skipped without a problem. Other aspects are dealt with in more depth in the course than in the book. Also the connections between the different topics and chapters are investigated more thoroughly in the course than in the book.

- The course consists of the following chapters:
- 0. Introduction
  - What is modelling?
  - About the role of knowledge representation and formal methods in computer science
  - Motivation for this course
- 1. Propositional logic
  - Syntax, semantics
  - Normalisation to CNF
  - SAT algorithms
- 2. Predicate logic
  - Syntax, semantics
  - Undecidability of deduction
  - Expressiveness
  - Extensions of predicate logic
  - Problem solving through logic inference systems
    - database model checking and query answering inference as model checking
    - model generation, model revision
    - theorem proving/deduction
  - Algorithms for grounding
- 3. Modelling of dynamic systems
  - The frame problem
  - Temporal formalisms: Linear Time Calculus (LTC), Event-B
  - Inference methods for Verification and problem solving for dynamic systems
  - Modelling on different levels of abstraction and the refinement principle.
  - Verification in the context of refinement
- 4. Verification by model checking
  - Motivation for verification
  - Temporal logics
    - linear time temporal logics (LTL): syntax, semantics, specification patterns, important equivalences, connectives, links with LTC (Linear Time Calculus)
    - Branching-time temporal logic (CTL): syntax, semantics, specification patterns, important equivalences, connectives
    - Comparison LTL and CTL
  - Model checking
    - model checking in CTL
    - SAT-solvers for model checking
    - model checking in LTL using automata-theoretic techniques"

14. MIT / USA

14.1. Professional certificate: Architecture and Systems Engineering: Models and Methods to Manage Complex Systems

14.1.1. Keywords

- Models in verification and validation
- What is a model
- Optimizing a model
- Bringing several models together

14.1.2. Course outline

- Week 1 : What is a model (4-5 hrs)
    - Get started (presentation of the course)
    - What is a model : defining models, making decisions with models
    - Graded activity (20 min)
    - Project (1.5 hrs)
- Week 2 : Making a model (4-5 hrs)
    - Making, optimizing a model, sensitivity in models
    - Graded activity (20 min)
    - Project (1.5 hrs)
- Week 3 : Joining several models together (4-5 hrs)
    - Bringing models together: promises and challenges
    - Multidisciplinary Design Optimization (MDO)
    - Choosing One Model or Several
    - Graded activity (20 min)
    - Project (1.5 hrs)
    - Webinar Q&A with the Faculty Director (1 hr), Yellowdig discussion forum
- Week 4 : Models in Verification and Validation (4−5 hrs)
    - Introduction to V&V, roles of Models in V&V
    - Developing a V&V Strategy Framework
    - When Are Models the Right V&V Strategy?
    - Graded Activity (20 min)
    - Project (1.5 hours)
    - Feedback survey

14.2. Engineering innovation design

14.2.1. Keywords

- Design thinking

14.2.2. Course outline

- Project-based seminar in innovative design thinking develops students' ability to conceive, implement, and evaluate successful projects in any engineering discipline. Lectures focus on the iterative design process and techniques to enhance creative analysis. Students use this process to design and implement robust voice recognition applications using a simple web-based system. They also give presentations and receive feedback to sharpen their communication skills for high emotional and intellectual impact. Guest lectures illustrate multidisciplinary approaches to design thinking.

14.3. FUNDAMENTALS OF SYSTEMS ENGINEERING

14.3.1. KEYWORDS

- V-model
- Verification and validation
- Requirements definition
- Design definition and optimization

14.3.2. COURSE OUTLINE

- General introduction to systems engineering using the classical V-model. Topics include stakeholder analysis, requirements definition, system architecture and concept generation, trade-space exploration and concept selection, human factors, design definition and optimization, system integration and interface management, system safety, verification and validation, and commissioning and operations. Discusses the trade-offs between performance, life-cycle cost and system operability. Readings based on systems engineering standards. Individual homework assignments apply concepts from class and contain both aeronautical and astronautical applications. Prepares students for the systems field exam in the Department of Aeronautics and Astronautics.

14.4. SYSTEMS ARCHITECTING APPLIED TO ENTERPRISES

14.4.1. KEYWORDS

- Architecting new and evolving sociotechnical enterprise
- Covers frameworks and methods for ecosystem analysis, stakeholder analysis
- Architecture design and evaluation

14.4.2. COURSE OUTLINE

- Focuses on principles and practices for architecting new and evolving sociotechnical enterprises. Includes reading and discussions of enterprise theory, contemporary challenges, and case studies of evolving enterprises. Covers frameworks and methods for ecosystem analysis, stakeholder analysis, architecture design and evaluation, and implementation strategies. Students work in small teams on projects to design a future architecture for a selected real-world enterprise.

14.5. ENGINEERING SYSTEMS ANALYSIS FOR DESIGN

14.5.1. KEYWORDS

- Decision and lattice analysis
- Definition of uncertainties
- Simulation of performance for scenarios

- Theory and methods to identify, value, and implement flexibility in design

14.5.2. Course outline

- Covers theory and methods to identify, value, and implement flexibility in design, also known as "real options." Topics include definition of uncertainties, simulation of performance for scenarios, screening models to identify desirable flexibility, decision and lattice analysis, and multidimensional economic evaluation. Students demonstrate proficiency through an extended application to a systems design of their choice. Provides a complement to research or thesis projects.

14.6. Air Transportation Systems Architecting

14.6.1. Keywords

- Architecting of air transportation systems
- Conceptual phase of product definition

14.6.2. Course outline

- Addresses the architecting of air transportation systems. Focuses on the conceptual phase of product definition including technical, economic, market, environmental, regulatory, legal, manufacturing, and societal factors. Centers on a realistic system case study and includes a number of lectures from industry and government. Past examples include the Very Large Transport Aircraft, a Supersonic Business Jet and a Next Generation Cargo System. Identifies the critical system level issues and analyzes them in depth via student team projects and individual assignments. Overall goal is to produce a business plan and a system specifications document that can be used to assess candidate systems.

14.7. Space Systems Engineering

14.7.1. Keywords

- Space system architectures
- Concepts of risk
- Interactions between subsystems in the context of a space system design

14.7.2. Course outline

- Focus on developing space system architectures. Applies subsystem knowledge gained in previous courses to examine interactions between subsystems in the context of a space system design. Principles and processes of systems engineering including developing space architectures, developing and writing requirements, and concepts of risk are explored and applied to the project. Subject develops, documents, and presents a conceptual design of a space system including a preliminary spacecraft design.

14.8. Engineering Apollo: The Moon Project as a Complex System

14.8.1. Keywords

- Historical exploration of the Apollo project

14.8.2. COURSE OUTLINE

- Detailed technical and historical exploration of the Apollo project to fly humans to the moon and return them safely to Earth as an example of a complex engineering system. Emphasizes how the systems worked, the technical and social processes that produced them, mission operations, and historical significance. Guest lectures by MIT-affiliated engineers who contributed to and participated in the Apollo missions. Students work in teams on a final project analyzing an aspect of the historical project to articulate and synthesize ideas in engineering systems.

14.9. FOUNDATIONS OF SYSTEM DESIGN AND MANAGEMENT

14.9.1. KEYWORDS

- foundations of systems architecture
- verification and validation systems safety
- stakeholder analysis, project planning and monitoring
- requirements definition
- organizational design
- foundations of project management

14.9.2. COURSE OUTLINE

- Presents the foundations of systems architecture, systems engineering and project management in an integrated format, through a synchronized combination of in-class discussion, industrial guest speakers, team projects, and individual assignments. Topics include stakeholder analysis, project planning and monitoring, requirements definition, concept generation and selection, complexity management, system integration, verification and validation, cost modeling, systems safety, organizational design and effective teamwork, risk management, and leadership styles. Restricted to students in the SDM program.

14.10. FOUNDATIONS OF SYSTEM DESIGN AND MANAGEMENT II

14.10.1. KEYWORDS

- Deepens the foundations of systems architecture, systems engineering and project management
- Transition from early conceptual design to detailed design and system integration

14.10.2. COURSE OUTLINE

- Deepens the foundations of systems architecture, systems engineering and project management introduced in previous courses though a synchronized combination of lectures, recitations, opportunity sets, guest speakers, and team projects. Topics emphasize the transition from early conceptual design to detailed design and system integration. Includes team-based exercises and design challenges. Restricted to students in the SDM program.

14.11. FOUNDATIONS OF SYSTEM DESIGN AND MANAGEMENT III

14.11.1. KEYWORDS

- Deepens the foundations of systems architecture, systems engineering and project management
- Transition from early conceptual design to detailed design and system integration

14.11.2. COURSE OUTLINE

- Presents advanced concepts in systems architecture, systems engineering and project management in an integrated manner through lectures, recitations, opportunity sets, guest lectures, and a semester-long team project. Topics emphasize complexity management, systems integration, verification, validation, and lifecycle management. Specific lifecycle properties addressed include quality, safety, robustness, resilience, flexibility and evolvability of systems over time. Additional topics include monitoring and control, the rework cycle, managing portfolios and programs of projects in a multi-cultural and global context, and managing product families and platforms. Restricted to students in the SDM program.

15. GEORGIA TECH / USA

15.1. SYSTEMS ENGINEERING CERTIFICATE – COURSE OUTLINE

- SYSTEMS ENGINEERING PROCESSES
  - Introduction to Systems Engineering Processes via case study analysis
- SYSTEMS ENGINEERING TOOLS AND TECHNIQUES
  - Application of tools and techniques throughout the systems lifecycle
  - Practical application to realistic scenarios
- SYSTEM DECOMPOSITION AND DEFINITION
  - Decomposition of system stakeholder needs through requirements definition, Concept of Operations and Use Case development
  - Further decomposition through functional analysis and architecture definitions and development
  - Trade studies and analysis of alternatives to support systems definition
- SYSTEM DESIGN ITERATION AND IMPLEMENTATION
  - System baseline management and design iterations
  - Verification and validation from concept and design through implementation, integration, and deployment
- SYSTEMS ENGINEERING PLANNING AND MANAGEMENT
  - Development of a Systems Engineering Management Plan consolidating processes, methods and tools utilized in scenario development
  - Risk analysis of cost, schedule and performance aspects of scenarios

15.2. ADVANCED SYSTEMS ENGINEERING CERTIFICATE – COURSE OUTLINE

- Deepening of Systems Engineering knowledge by a choice of four courses among:
  - Modeling and Simulation for Systems Engineering
    - The modeling and simulation development process
    - The types and uses of data in simulations, as how verification and validation supports simulation use
    - Systems modeling language (SysML)
    - Different types of simulation methodologies: continuous, discrete, Monte Carlo, agent-based, system dynamics, games, and virtual worlds
    - The systems-engineering lifecycle and how models and simulations fit into the process
  - Introduction to Human Systems Integration
    - HSI program planning, requirements, and metrics
    - HSI analyses
    - HSI domains
    - Tradeoffs between domains
    - HSI test and evaluation methods
  - Fundamentals of Systems Architecting
    - Systems engineering context
    - An introduction to systems architecting
    - System of systems (SoS) architectures and classification
    - Architecting models
    - Heuristics as tools
    - Architecture framework
    - Design activities

        - Modeling methods
        - Software architecture
        - Agile architecture methods
        - Quality evaluation
        - Role of the systems architect
    - Applied Systems Engineering Laboratory
        - Space mission lifecycle and architecture
        - Mission and systems baselines
        - Functional baseline
        - Space mission baselines development
        - Mission architecture development
        - Design to baseline
        - Space mission baselines verification
        - Space mission cost estimation
        - Build to baseline
        - As built baseline
        - Robust design and space mission validation
        - Robust design
    - Cybersecurity: A Systems Approach
        - Information security principles
        - Systems engineering approach
        - Vulnerabilities, threats, and exploitations
        - Protections and defenses
        - Cryptography
        - Risk reduction
    - Creativity Hacks - Psychology and Tools for Creative Thinking
        - The systems model for creativity
        - The psychology and neuroscience of creativity
        - Tools and techniques for individual creativity
        - How to facilitate group creativity
        - A simple model for improving one's personal creativity
        - A group creativity and facilitation case study based on a popular visual problem solving methodology
    - Fundamentals of Cyber Systems Test and Evaluation
        - Cyber domain and defenses introduction
        - Developmental, operational, and interoperability cyber testing
        - Test planning
        - Test types
        - Test execution and control
        - Data management
    - Design of Experiments (DOE) I: Introduction to DOE
        - The advantages of using DOE
        - DOE process setup and solution steps including randomization
        - Derivation of transfer functions to quantify contributions of inputs (factors) to outputs (responses)
        - Full factorial and fractional factorial experiments, screening designs, and optimal designs
        - Solution of DOE problems using examples from Statapults, computer games, and simulations
        - DOE solutions using various software packages
        - Various design and randomization techniques

- Scientific Principles of Test and Evaluation and Optical Systems Engineering
  - Phases of T&E and the relationship to the acquisition lifecycle
  - T&E as part of systems engineering
  - Detecting and resolving problems early
  - T&E approach derived from mission and task decomposition
  - Scientific methods to support T&E, including statistics, graphical analyses, and design of experiments
  - Test plans and test reports supported by scientific methods
  - M&S overview, including M&S types, sources, and uses in the acquisition cycle
- Model-Based Engineering Fundamentals: Understanding SysML Models
- Model-Based Engineering Fundamentals: Creating SysML Models
  - MBE and MBSE context and motivation
  - How to understand upfront concepts (system objectives), structure and behavior concepts, and cross-cutting concepts in a SysML system model
  - Leading-edge applications and deployment considerations

15.3. APPLIED SYSTEMS ENGINEERING (ASE)

15.3.1. KEYWORDS

- System of systems Architecture
- Analysis & Synth-Sensors
- Analysis & Synth-InfoSys
- Analysis & Synth-HIS
- Modeling
- Adv Topics SE – SysML
- Leading system engineering teams

15.3.2. COURSE OUTLINE

- Fund Modern Sys Eng. 3 Credit Hours.
  - Explore a wide range of modern systems engineering principles and development methodologies. Address requirements engineering, systems definition, design and analysis, implementation, operation, and technical management.
- Systems Design/Analysis. 3 Credit Hours.
  - Introduce emerging techniques for systems and systems-of-systems analysis including IPPD, DOE, Taguchi methods, response surface equations, multi-attribute decision making, and concept feasibility assessment.
- Modeling/Sim Sys Eng. 3 Credit Hours.
  - Introduction to modeling and simulation for systems engineers. Topics include problem formulation, conceptual modeling, simulation methodologies, verification and validation, DOE, simulation execution, and output analysis.
- Leading Sys Eng Teams. 3 Credit Hours.
  - Systems engineering processes provide a model for successfully managing complex systems. Learn to apply management and development techniques used for successful commercial and government programs.
- Adv Topics SE - SysML. 3 Credit Hours.
  - This core elective introduces SymML as a system modeling and design tool, with example applications, guidelines for application, and student projects on implementations in practice.

- Systems Engineering Lab. 3 Credit Hours.
  - Application of working knowledge of systems engineering techniques applied to a “case study” in an applicable domain.
- Analysis & Synth-Vehicle. 3 Credit Hours.
  - Vehicle Preliminary Design involves design iteration with disciplinary physics-based methods and tools. Includes geometry and databases from conceptual design, six DOF modeling, analysis, and synthesized baseline.
- System of Systems & Arch. 3 Credit Hours.
  - Develop a broader understanding of the interdependencies and interoperability issues, interfaces, and processes for creating and defining Systems Architecture for complex systems.
- System Lifecycle & Integ. 3 Credit Hours.
  - System preliminary design must address product and process design throughout system lifecycle from integration through manufacturing to phase-out along with interfaces to other emerging systems.
- Capstone Complex Systems. 3 Credit Hours.
  - Student teams apply methods and techniques taught throughout the program to conduct complex system Conceptual Design based on requirements provided in a Request for Proposal.
- Analysis & Synth-Sensors. 3 Credit Hours.
  - Defines, classifies, and examines technology used in stand-alone sensor systems. Centers on system-engineering trades useful in designing systems of sensors and systems of systems.
- Analysis & Synth-InfoSys. 3 Credit Hours.
  - Tools and approaches for analysis and synthesis of enterprise information systems. Topics include user-centered requirement, scenario-based design, UML, network/communications, iterative prototyping, and enterprise support.
- Analysis&Synth-HSI. 3 Credit Hours.
  - Human Systems Integration Analysis and Synthesis, a PMASE complex systems elective, ensures human-related technical issues are properly addressed during system definition, design, development, and implementation."

16. STANFORD UNIVERSITY / USA

16.1. HOW TO DESIGN A SPACE MISSION: FROM CONCEPT TO EXECUTION

16.1.1. KEYWORDS

- variety of mission types, for communication, navigation, science, commercial, and military application

16.1.2. COURSE OUTLINE

- Space exploration is truly fascinating. From the space race led by governments as an outgrowth of the Cold War to the new era of space commercialization led by private companies and startups, more than 50 years have passed, characterized by great leaps forward and discoveries. We will learn how space missions are designed, from concept to execution, based on the professional experience of the lecturer and numerous examples of spacecraft, including unique hardware demonstrations by startups of the Silicon Valley. We will study the essentials of systems engineering as applicable to a variety of mission types, for communication, navigation, science, commercial, and military applications. We will explore the various elements of a space mission, including the spacecraft, ground, and launch segments with their functionalities. Special emphasis will be given to the design cycle, to understand how spacecraft are born, from the stakeholders' needs, through analysis, synthesis, all the way to their integration and validation. We will compare the current designs with those employed in the early days of the space age, and show the importance of economics in the development of spacecraft. Finally, we will brainstorm startup ideas and apply the concepts learned to a notional space mission design as a team.

16.2. OPERATION OF AEROSPACE SYSTEMS

16.2.1. KEYWORDS

- use of tours, guest speakers, flight simulation, and hands-on exposure to systems used by pilots and space mission operators

16.2.2. COURSE OUTLINE

- This course provides a connection with the products of aerospace design through the use of tours, guest speakers, flight simulation, and hands-on exposure to systems used by pilots and space mission operators. We discuss real-world experiences with operators of spacecraft and launch vehicles, and we hear from pilots of manned and unmanned aircraft. Skills required to operate systems in the past, present, and future are addressed. Students will also develop an appreciation of the effects of human factors on aviation safety and the importance of space situational awareness. Anticipated tours include an air traffic control facility and a spacecraft operations center.

16.3. SPACECRAFT DESIGN

16.3.1. KEYWORDS

- spacecraft configuration design
- Design integration and operations.
- mechanical design
- Structure and thermal subsystem design

16.3.2. COURSE OUTLINE

- The design of unmanned spacecraft and spacecraft subsystems emphasizing identification of design drivers and current design methods. Topics: spacecraft configuration design, mechanical design, structure and thermal subsystem design, attitude control, electric power, command and telemetry, and design integration and operations.

17. THE UNIVERSITY OF CALIFORNIA, BERKELEY / USA

17.1. ENGINEERING DESIGN AND PROTOTYPING: PEDAGOGY & ASSESSMENT

17.1.1. KEYWORDS

- integrative learning and the role of cognition and the learning sciences in the practice of engineering design

17.1.2. COURSE OUTLINE

- Provide learners the opportunity to question (usually tacit) assumptions about what engineering is, what the purpose and process of engineering education is, and who gets to be an engineer.
  - Understand design as a pedagogy for integrative learning and the role of cognition and the learning sciences in the practice of engineering design and prototyping.
  - Provide the participants with an understanding of theories and practices in content, assessment, and pedagogy for teaching engineering design and prototyping.
  - Familiarize learners with quantitative and qualitative methodologies for data analysis associated with the assessment of design and prototyping interventions.
  - Promote critical thinking and a social construction of knowledge by having face-to-face and online discussions of readings from a variety of sources.

17.2. OTHER COURSES

Berkeley has other courses that somehow did not get into the benchmark, they will be included in an updated version of this report in 2020.

18. UNIVERSITY OF MICHIGAN ANN ARBOR (UM) / USA

18.1. MASTER EN INGENIERIE SYSTEME + DESIGN

18.1.1. KEYWORDS

- Systems Engineering + Design Core (9 credits)
- Design-Focused Elective (3 credits)

18.1.2. COURSE OUTLINE

- Requires 30 total credits of coursework with:
  - At least 24 credits* in letter graded (A-E) courses.
  - At most 6 credits may be in letter graded (A-E) approved courses at the 400 level.
  - At least 6 credits toward a practicum (graded Satisfactory/Unsatisfactory).
- Systems Engineering + Design Core (9 credits): Breadth
  - Introduction to Systems Engineering (Offered Fall, Winter, Spring/Summer) Online, On-campus
  - Development and Verification of System Design Requirements (Offered Fall) Online, On-campus
  - System Architecting, Concept Development and Embodiment Design (Offered Winter) Online, On-campus
- Student-Selected Electives (12-15 Credits): Depth
  - At least 3 credits must come from a systems engineering elective
  - At least 3 credits must come from a design-focused elective
  - The remaining 6-9 credits are at the student's discretion, with program director approval.
- Systems Engineering Elective (3 credits)
  - Risk Analysis I (Offered Winter Term) Online, on-campus
  - Software Systems Engineering (Offered Winter Term) Online, on-campus
  - Design for Six Sigma (Offered Winter Term) Online, on-campus
- Design-Focused Elective (3 credits)
  - Design Optimization (Offered Winter) Online, on-campus
  - Analytical Product Design (Offered Fall) On-campus
  - Marine Design (Offered Winter) On-campus
  - Nuclear Core Design (Offered Winter) On-campus
  - Design of Digital Control Systems (Offered Winter) On-campus
  - Design of Environmental Engineering Systems (Offered Fall) On-campus
  - Space Systems Design (Offered Winter) On-campus
  - Multidisciplinary Design Optimization (Offered Winter) On-campus
- Other Elective Specialties
  - Automotive Engineering
  - Manufacturing
  - Energy Systems Engineering
  - Aerospace Systems
  - Note: Students may develop their own specialties based on their interests. For further course descriptions, go to the College of Engineering Bulletin.

19. THE UNIVERSITY OF HONG KONG / HONG KONG

19.1. MSc PROGRAMME IN SYSTEMS ENGINEERING AND ENGINEERING MANAGEMENT

19.1.1. KEYWORDS

- Models and Decisions with Financial Applications
- Information Technology Management
- Principles of Engineering Management
- Information Technology Management

19.1.2. COURSE OUTLINE

- Required Courses
  - Principles of Engineering Management
    - fundamental principles of managing engineering and industrial organizations
    - application of quantitative and qualitative approaches in the practice of engineering management.
    - Quantitative modelling and solution techniques for strategic and operational problems
    - role of strategic management, strategy formulation, and strategy implementation
    - Other strategic issues involving innovation and ethics are also addressed.
  - Information Technology Management
    - The challenges, techniques and technologies associated with the management of information technology (IT) in a competitive environment
    - The linkage of IT to business strategy and business process re-engineering
    - Different types of information systems: MIS, DSS, TPS.
    - Information technology concepts: networking, database, batch and distributed processing
    - Development Process and Information system planning
    - Systems project management and control
    - IT acquisition, budgeting and deployment
    - Performance evaluation and audit
    - Operations management, privacy and security.
  - Models and Decisions with Financial Applications
    - Models of risks
    - Utility functions, and mean-variance theory
    - Probability models and price dynamics of securities
    - Geometric Brownian motion, Ito's lemma, Black-Scholes model.
    - Capital asset pricing. Risk hedging. Optimization techniques.
    - Applications to investment and portfolio management. The emphasis is on mathematical modelling, analysis, and computation.
- Elective Courses
  - Students must complete 5 elective courses but they cannot take more than 2 from each of the following three areas
  - Project in SEEM
  - Under the supervision of the course instructor, students carry out a practical project in Systems Engineering & Engineering Management.
  - Company visits and field studies may be required to help students understand different business operating environments and their implications for solution development.
- Area I: Engineering Management
  - Manufacturing and Service Operations Management

- Engineering Economics
  - Quality Assurance and Control
  - Project and Technology Management
  - Logistics Management
  - Supply Chain Management
- Area II: Information Systems
- Expert Systems and Decision Support
  - Overview of management support systems.
  - Client/Server Information Systems
  - Open Systems and Electronic Commerce
- Area III: Financial Engineering
  - Stochastic Investment Models
  - Financial Analysis and Security Trading (CEF No. 23Z02195-3)
  - Computational Intelligence in Financial Information Systems
  - Computational Finance

19.2. MSC INDUSTRIAL ENGINEERING AND LOGISTICS MANAGEMENT

19.2.1. KEYWORDS

- collect and analyse research data and use appropriate engineering tools
- investigate new and emerging system models and technologies
- solving problems in engineering systems and the ability to assess the limitations of particular cases

19.2.2. COURSE OUTLINE

- System analysis and design :
  - The ability to use fundamental knowledge to investigate new and emerging system models and technologies
  - The ability to apply appropriate models for solving problems in engineering systems and the ability to assess the limitations of particular cases
  - The ability to collect and analyse research data and use appropriate engineering tools to tackle unfamiliar problems, such as those with uncertain or incomplete data or specifications, by the appropriate innovation, use or adaptation of engineering analytical methods
  - The ability to apply original thought to the development of practical solutions for products, systems, processes or services

20. KEIO UNIVERSITY / JAPAN

20.1. MASTER OF SYSTEM ENGINEERING / MASTER OF SYSTEM DESIGN AND MANAGEMENT

20.1.1. KEYWORDS

- System architecting and integration
- System verification and validation
- Systems approach for business systems
- Modeling and simulation of systems
- Introduction to system design and management
- Research on system design and management
- Introduction to system design and management
- Project management

20.1.2. COURSE OUTLINE

- Required Subjects
  - Introduction to system design and management (2)
  - System architecting and integration (2)
  - System verification and validation (2)
  - Project management (2)
  - Design project (4)
  - Research on system design and management (2)
- Major Subjects
  - Communications (2)
  - Statistics and data processing for system design (2)
  - Systems approach for business systems (2)
  - Modeling and simulation of systems (2)
  - Special lectures 1, 2 (2)
  - Practice of system design and management (2)
  - Foundation of model-driven systems development (2)
  - Model-based prediction and control of systems (2)
  - Network and database systems (2)
  - Software engineering (2)
  - Environmental system design (2)
  - Risk management of technological systems (2)
  - Electronics system safety (2)
  - Human factors (2)
  - Human relations (2)
  - Human interface (2)
  - Virtual design (2)
  - Methodology of creative decision makings (2)
  - Management and financial strategy (2)
  - Systems of finance and currency (2)
  - International political economy: discussions on its systems (2)
  - Systems of intelligence (2)
  - Competitive intelligence (2)
  - Supply chain management and business game (2)

- Business system engineering (2)
- Medical system and research development of medication 2 (2)
- Internship 1, 2 (2)

20.2. PRACTICE OF SYSTEM DESIGN AND MANAGEMENT

20.2.1. KEYWORDS

- System life cycle and V model 'practitioner'
- System Architecture Practitioner
- Context analysis and Stakeholder analysis Practitioner
- System Integration and V & V

20.2.2. COURSE OUTLINE

- Introductory lesson and simple trial exercises “practitioners” - How to cooperate with system design and management classes, How to read the textbook (INCOSE handbook, Visualizing Project Management) , Introduction of the class situation up to last year, introduction of the students' voices, and practice simple exercises.
- System life cycle and V model 'practitioner' - Look back on the results of the last exercise and check what we learn in this lesson in a group discussion format . We will learn something that is necessary for system design and management, especially “technology”.
- Required development, teaming “practitioner” - "Request" required for the system is not something to hear from customers or sponsors (investors) I will learn something. In addition, system design and management will greatly influence the goodness of team work, so we will experience team making for group work through this lesson. The team will develop and implement strategies to interact with enterprises since system development.
- Context analysis and Stakeholder analysis “Practitioner” - To make a request, it is necessary for the system (or service) to operate as the context and system to be used It is important to organize the Stakeholder. We will create essentially necessary requirements by investigating issues and group discussions.
- Through group work based on initial request presented from customer (one faculty is in charge) through CONOPS and system request “practitioner” workshop Create CONOPS. I will practice how to organize the method to realize the request defined here as a system request.
- System Architecture “Practitioner” - Practice at the workshop on how to create an architecture to build up the results specified as system requirements as a system. In particular, we will learn how to examine feasibility in practical form.
- Decision Gate and Project Implementation Plan - Practice workshop on cooperation method of project plan and system engineering so as not to cause delivery time or excess cost. Originally (actual SE site) will be carried out before the system architecture, but will be carried out after the architecture to recognize the importance.
- Architecture reconsideration, system design “practitioner” - We decide Item (Component) for realizing the system architecture to the minimum level through workshop.
- Procurement and integration (parts) 'practitioner'
- System Integration and V & V - Validation and Verification via Workshop

20.3. SYSTEM SCIENCE AND PHILOSOPHY

20.3.1. KEYWORDS

- Introduction to System Architecture and Integration
- Foundation of Soft System

20.3.2. COURSE OUTLINE

- Philosophy of guidance and system “practitioner teacher” - We will present the whole picture on the science and philosophy of the system.
- Foundation of Soft System - We describe the fundamentals of Soft Systems methodology proposed by Checkrand et al.
- Philosophy of the mind (passive consciousness hypothesis) “Worker teacher - We describe the passive consciousness hypothesis advocated by Maeno. Based on “How to make thinking brain power”, I will describe the relation between system engineering, system science and system philosophy.
- History of system science and philosophy 1 “practitioner teacher” - We will describe the history of system science and philosophy.
- Basic of ethics “practitioners' faculty” - We will describe the foundation of ethics as a philosophy (consequentialism and non-consequentialism).
- Solution for Ethical Problems “Professor of Workers” - We describe a technique such as Seven Step Guide which is a technique for solving ethical problems.
- Ethical Problem Solving Techniques and Ethics of Fukuzawa Yukichi “Business Professor” - We will present the vision of Yukichi Fukuzawa.
- Foundation of happiness science “practitioner teacher” - When we arrive at the foundation of happiness science, I will state it.
- System Life Theory “Professor of Workers” - We will explain the concept of “life-changing” proposed in the 21st century COE program.
- Complex System and Small World “Working Teacher” - We will explain the cutting edge of complex systems and information systems such as complex science, chaos and small world.
- Neural network “practitioner teacher” - We will describe the neural network and the brain.
- Foundation of Happiness Science “Professor of practitioners”

20.4. MODEL-BASED PROCESS AND SYSTEM MANAGEMENT

20.4.1. KEYWORDS

- value-driven systems engineering
- Request model: Expansion from value analysis model to request analysis tree

20.4.2. COURSE OUTLINE

- Introduction to value-driven systems engineering - In society it is required to provide products and services that maximize value. In order to provide such a system, it is necessary to clearly consider the relationship between business and systems engineering. In this lecture, while discussing INCOSE Vision 2025, we discuss the direction that systems engineering should head.
- Fundamentals of Systems Engineering - System functional representation and logic thinking are important as the basis of systems engineering. In addition to learning the input / output relation of the system and the meaning of the state, learn important characteristics of the system such as controllability, observability, stability.

- Concept design based on model - In Systems Engineering, it is first required to clarify the concept, but this stage is not necessarily discussed enough. Correctly showing the concept to the business, management, and policy makers will have a significant influence on subsequent stages of system development. In this lecture we will discuss model-based concept design.
- Exercise: Concept design based on model - Learn conceptual design based on model through exercise. Here, we utilize SysML (Systems Modeling Language) which describes system model by structure, behavior, request, parametric constraint.
- Industrial Internet, INDUSTRIE 4.0 - New concepts such as Industrial Internet, INDUSTRIE 4.0 are shown from the United States, Germany and others. Consider how Cyber Physical System and Internet of things are connected to these new concepts from the viewpoint of systems engineering.
- Exercise: Consider the concept related to Industrial Internet, INDUSTRIE 4.0 - Exercise to think about new concepts related to Industrial Internet, INDUSTRIE 4.0. As a subject, I read the materials of Industrial Internet or INDUSTRIE 4.0, and associate this concept with master's research, think about a system that drives value.
- Introduction to value-driven projects - Why is now a value-driven project design needed in the world of rapidly changing businesses, how to use models We will talk about how to visualize the business system, and outline the method necessary for management of the process based on the model to create value.
- Value design: explanation and exercise of value analysis model, extraction of stakeholders and value design of stakeholders - In the process for promoting value-driven projects Start with the design of value. In this second lecture, which will be the second time in the second half, we will explain what the value analysis model is, extract exercise key stakeholders (stakeholders) by exercise, draw value and lead the design of value.
- Design of value: detailed value of stakeholders, relationship between stakeholder value and project purpose - In this third lecture, which is the third time in the second half, Refine (refine) the value of stakeholders through exercises and show ways to connect the value of stakeholders to the purpose of the project.
- Request model: Expansion from value analysis model to request analysis tree - Explain the relationship between the request model created up to the last time and the process model to be created . In addition, through exercise, while creating a process model, request it again from the request model, and experience the iteration (repetition) between models such as verifying the request with the process model.
- Process Model Exercise: Detailed Requirement Model by Process Model - Explain the relationship between the request model created up to the last time and the process model to be created . In addition, through exercise, while creating a process model, request it again from the request model, and experience the iteration (repetition) between models such as verifying the request with the process model.
- Refining Requirements by Request Model and Project Planning - How to formulate project planning (activity model) from the value model, request model, process model created so far I will explain it. Also, by exercise, prepare a goal description. In this lecture, which will be the final round, we will discuss how the process to create the value developed throughout will have a positive impact on the activity process (PDCA).

20.5. ADVANCED SPACECRAFT SYSTEMS DESIGN

20.5.1. KEYWORDS

- SysML to describe the system model
- Mission and system design
- Concept Design Workshop

20.5.2. COURSE OUTLINE

- Introduction to Learn spacecraft system design through real nano-satellite design example "UNIFORM". Introduction to "UNIFORM" Project.
- Mission and system design - UNIFORM project mission and system design
- Concept Design Workshop - Two-week workshop to exercise concept design of a spacecraft mission. Based on the fundamental knowledge discussed in class, students conduct mission definition, requirement analysis, software/hardware design, mass/power/link budget analysis.
- UNIFORM attitude and orbit control subsystem (AOCS)
- UNIFORM command and data handling subsystem (CDH)
- UNIFORM communication (COM) subsystem
- UNIFORM ground system design
- UNIFORM electrical power subsystem design
- UNIFORM structure subsystem design
- UNIFORM thermal subsystem design
- UNIFORM integration and test
- Concept Design Workshop - Two-week workshop to exercise concept design of a spacecraft mission. Based on what was covered in the course, students conduct mission definition, requirement analysis, software/hardware design, mass/power/link budget analysis as well as cost analysis.

20.6. INTRODUCTION TO SYSTEM DESIGN AND MANAGEMENT

20.6.1. KEYWORDS

- System Engineering: Architectural Design
- Business System Design
- Organizational system design
- Social system design

20.6.2. COURSE OUTLINE

- Outline of SDM Study - I will describe the whole picture and contents of contents learned by SDM. Also, we will explain the basic terms.
- Logical thinking and the basis of system thinking - Logic which is the thinking method which is the basis of every intellectual activity We introduce logical thinking and system thinking. It is important to clarify the concept of MECE (Mutually Excusive Collectively Exhaustive), which is the basis of logical thinking, and the persuasive speech hidden in everyday languages, pay attention to unconscious assumptions, unreasonable remarks, etc., and make it as accurate as possible We introduce the logic to grasp the facts. I will present a clear presentation technique based on MECE structuring (pyramid structure). Also, in the workshop style, exercises by group discussion will be carried out.
- System Thinking - For logical thinking (Logical Thinking) which is a thinking style of decomposition system, causal system Learn the basic idea of system thinking (System Thinking) which is the thinking style of Master the causal loop diagram (Causal Loop Diagram) as an analytical tool that visually expresses the causal relation between elements and be able to construct dynamic hypothesis for the mechanism of occurrence of problems at the initial stage of the project As a target. Also, in the workshop style, exercises by group discussion will be carried out.
- System Engineering: General Theory and Development Management - Outline the basic thinking and development management of Systems Engineering . Also, in the workshop style, exercises by group discussion will be carried out. Promote understanding through exercises.

- System Engineering: Requirement Analysis - Explain the fundamental idea about the basic requirement analysis, I will introduce the method with examples. Also, in the workshop style, exercises by group discussion will be carried out. Promote understanding through exercises.
- System Engineering: Architectural Design - Explain the basic concept of architecture design, I will introduce the method with examples. Also, in the workshop style, exercises by group discussion will be carried out. Promote understanding through exercises.
- System Engineering: Integration - Explain the basic idea about the fundamentals of integration, about processes and methods I introduce it with actual examples. Also, in the workshop style, exercises by group discussion will be carried out. Promote understanding through exercises.
- Business System Design - Explain the design of the business system using the system engineering concept. Also, in the workshop style, exercises by group discussion will be carried out. Understanding through exercises.
- Organizational System Design - Explain the design of the organization system using the system engineering concept. Also, in the workshop style, exercises by group discussion will be carried out. Understanding through exercises.
- Social System Design - Explain the design of social system using system engineering concept. Also, in the workshop style, exercises by group discussion will be carried out. Understanding through exercises.
- Current situation and future of SDM - As we ask questions and opinions about the whole SDM, Discuss the issue of the current situation of SDM and future image with students and faculty members.

20.7. SYSTEM ARCHITECTING AND INTEGRATION

20.7.1. KEYWORDS

- Introduction to System Architecture and Integration
- System Architecture and Integration for Social Systems
- Overview of Systems Engineering Process and MBSE
- System integration complexity

20.7.2. COURSE OUTLINE

- Introduction to System Architecture and Integration - A whole process of systems engineering and the purpose of this lecture
- Overview of Systems Engineering Process and MBSE
- System Architecture and Integration for Social Systems DAR, VAR in Systems Engineering Process - Technical Systems Engineering and Example for Vehicle Development
- System Architecture and Integration for Software Systems
- Systems Engineering Process
- Requirement engineering
- Good architecture
- System integration complexity

20.8. INTRODUCTION TO SYSTEM DESIGN AND MANAGEMENT

20.8.1. KEYWORDS

- Architectural design
- Requirements analysis

- Logical Thinking
- Organizational system design
- Social system design
- Business system design

20.8.2. COURSE OUTLINE

- Introduction to lectures in SDM - In this class, meanings of important terms used in SDM are explained. Contents of core courses are briefly explained as well.
- Logical Thinking - Logical Thinking is the fundamental skill to handle a system. In this lecture, students learn the basic knowledge of logical thinking including MECE (Mutually Exclusive Collectively Exhaustive) and pyramid structure.
- System Thinking - System Thinking is an essential measure to visually analyze causal relations within a system.The goal of the lecture is to master how to draw a Causal Loop Diagram (CLD).Textbook: “Business Dynamics”, J. D. Sterman, McGraw-Hill.
- Introduction to Systems Engineering - This lecture covers the introduction of systems engineering and requirement analysis which is first step of systems engineering.
- Requirement Analysis - Requirement Analysis is the activity to clarify the requirement of system. Through this lecture, you can learn the requirement analysis process and method through workshop.
- Architectual Design - Architectural design is the activity to clarify specification of elements of system and interfaces among elements by allocating function and performance required in system to the elements.
- Integration, Verification and Validation - Integration is the activity to integrate the implemented subsystem into the system. Verification and Validation is the activity to confirm the system implemented correctly.
- Business System Design - Apply systems engineering approach to business system design.
- Organizational System Design - Apply systems engineering approach to organizational system design.
- Social System Design - Apply systems engineering approach to social system design

20.9. SYSTEM ARCHITECTING AND INTEGRATION

20.9.1. KEYWORDS

- Architecting in space system development
- Technical system development
- Policy proposal of social system

20.9.2. COURSE OUTLINE

- SA & I Overall Review and SA & I in Technical System Development: Request and Integration, Verification, Validation - In the first half of the lecture, what can be learned throughout the relevant core subjects , We will outline what kind of learning effect can be expected. In the latter half, we will explain what we need to do for system integration, regarding technical system development, what good requirements, architecture, design are for the system.
- SA & I in technical system development: Request and integration, verification, validation - Securing traceability, clarifying the method of verifying system requirements, toward system integration I will explain what I should consider. In particular, we will describe the system analysis which the SE handbook was revised to 4th Edition and added.
- SA & I in Technical System Development: Dual Vee Model and Automobile Development -) As a development model, we will explain the Dual Vee model and also introduce the Dynamic Dual Vee To introduce the process of car development.

- Utilization of model base in technical system development - Explain model-based systems engineering that promotes systems engineering by exploiting system model representation. We introduce SysML, which is one of model notation, and discuss the effect of thinking on a model basis.
- Architecting and integration in space system development - Explain architecting and integration while utilizing architecting cases in space system development.
- System of Systems Architecture - Understanding what System of Systems (SoS) is and how to think about building SoS architecture, and SoS's Consider how to do management for good because of discussion.
- Group work setting and how to approach it - Explain the content of the group work to be addressed as the final task and show the policy towards SA & I initiatives , Grasp the request, set the problem and thinking to lead to a solution. In addition, we will conduct a comprehensive discussion on SA & I lecture in general. I will explain the most important and difficult problem grasp and request analysis in the system approach of social system with particular attention to the characteristics of system boundary identification.
- SA & I in Policy Proposal of Social System: Understanding Problems, Requirement Analysis: Clarification of Boundary - In the systems approach of social systems, the most important and difficult problem grasping and demanding Analysis will be explained with particular attention to features in system boundary identification.
- SA & I in Policy Proposal of Social System: Hierarchy of Goals, Downward System Level (Analysis): Exploring Feasibility - Requirements Analysis of Systems Approach of Social System We will explain the hierarchy of goals that will smoothly lead to the derivation of the design proposal, and how to get down the system level in the analysis, exploring feasibility in real problems. Furthermore, while touching SE VISION 2025, I will touch on the modern meaning of social system analysis.
- SA & I in Policy Advocacy of Social System: Policy Alternatives Derivation, Policy Recommendations: Comparative Evaluation from the Viewpoint of Realization as Required - Process of Design of Systems Approach of Social System We will explain the methodology that can narrow down while comparing and evaluating from the viewpoint of feasibility based on the policy design perspective as well.
- SA & I in software development: requirement analysis, external design, internal design, implementation, testing - architecting and integration of software systems for learn a series of processes of software development. Specifically, the system targets the requesting analysis of a software system performs clarity, the external design while checking the customer's request, further performs internal design, after its implementation, learn how to testing.
- SA & I in software development: Agile development - In software development, specifications often change due to customer policy changes and changes in circumstances surrounding the system, resulting in a large design or they are forced to change there be or no longer has to be completed earlier than scheduled. Learn about agile development that can respond promptly in such a case.
- Result presentation of group work and feedback from the teacher in charge - We will present the process and results of SA & I in the group with the given theme . Learn SA & I through feedback from the instructor in charge.

20.10. SYSTEM VERIFICATION AND VALIDATION

20.10.1. KEYWORDS

- Language Understanding of V & V "Practitioner"

20.10.2. COURSE OUTLINE

- Introduction and overview of classes “Actor” - We will establish relationships with other lectures of the SDM Graduate School and the overall structure of the lecture. In addition, we introduce system design and failure cases in management due to V & V shortage and failure.

- Language Understanding of V & V “Practitioner” - to verify, to validate is not exceptionally special in English-speaking countries. To avoid thinking hard about V & V so as not to cause allergy, this time learn about two V as a daily term. In trying to advance research with diverse themes, we try to convey an indispensable point of view.
- V & V “practitioner” for social center system - On the verification and validation of problems and solutions of social systems, first of all the characteristics and points to keep in mind are “ Research design (DSI) controversy “as key. We also look at the diversity and the characteristics of the combination of object and method of verification and validation of social system.
- Planning and Implementation of V & V “Practitioner - A concrete example on how V & V plans should be developed and implemented when implementing the system design and management Explain using it. We will ask questions related to V & V in advance by e-mail and respond and discuss them.
- Reconfiguration of V & V's concept “practitioner” - By rethinking V & V concretely, we will re-arrange V & V's thinking. We will ask questions related to V & V in advance by e-mail and respond and discuss them.
- V & V using the social survey law (part 1) “practitioner” - A society for correctly valuing society's overall systems and services from the viewpoints of both needs and seeds Describe various methodologies of the survey and explain points and precautions while giving examples.
- V & V “practitioner” - using questionnaires and interviews V and V case using multivariate analysis on relationships with qualitative concepts such as culture and culture and objective indicators Will be described.
- V & V using the social survey law (part 2) “practitioner” - A society for correctly valuing society's overall systems and services from both viewpoints of needs and seeds Describe various methodologies of the survey and explain points and precautions while giving examples.
- V & V Case Study: Workshop - What kind of V & V is carried out for each case based on past case on V & V by “Worker” - group work Discuss what it should have been.
- V & V “practitioner” using By simulation technology - Case of V & V etc. by virtual reality technology as simulation including technical system, V & V of social system, human behavior Will be described.
- V & V Case Study: V & V and Case Analysis of SDM Graduate School Initiative, Establishment and Operation “By Practice” - Based on the case study, establishment and operation of the SDM Graduate School I will show you what kind of V & V was carried out and what result and consideration was gained.

20.11. FOUNDATION OF MODEL - DRIVEN SYSTEMS DEVELOPMENT

20.11.1. KEYWORDS

- Model Based Requirements Management and Analysis
- SysML
- Project management with SysML

20.11.2. COURSE OUTLINE

- Outline of system engineering support language - In this class we introduce SysML language and utilize SysML for system modeling How to do.
- Outline of system engineering support language - Study on how to utilize SysML for system modeling, see the whole language After understanding, understand basic concepts.
- Outline of process and methodology of system engineering - We introduce the basic modeling method. Describe the methodology for creating a harmonious system. In this methodology, emphasis is placed on conceptual design, and SysML grasps and evaluates the whole of the product.
- Model Based Requirements Management and Analysis - Model-based approach to requirement management work done early in the development stage Discuss. Fulfillment of system requirements and objectives is a basic criterion for product success, and explains the effectiveness of model-based approach to this.

- System configuration modeling with SysML - Describe the notation describing the configuration of the 2nd C3N14 system. SysML supports conceptual design. For conceptual design, support that crosses engineering specialty areas is necessary, and we will introduce methods to describe these types of designs and develop them.
- Modeling of operation by SysML: System contact - Consider a method to describe the operation of the first system. The goal is to actually understand the system communication by using the operation notation called an interaction diagram.
- Functional verification of systematic system - Information on the structure and operation of three-time C3N14 system is summarized, and the function and configuration of the system Explain the relationship clearly. We introduce a method to easily verify the functions that the system configuration should satisfy while developing conceptual design.
- Constraint modeling - We introduce a method for describing constraints among attributes of 4 limit C 3 N 14 system. Complex systems have characteristics that can be decomposed without fail. Therefore, work to define and analyze such characteristics occurs. We will describe notation dealing with dependency between each property.
- Modeling behavior by SysML: System state and system activity - Operation modeling using SysML will be described in detail . In particular, it introduces the notation for defining the state of the system. In addition, we also introduce techniques for describing asynchronous activities in the system. Explain the notation that accurately represents the behavior of a complex system.
- Project management by SysML
- SysML exercise - Exercise throughout and clarify the functional requirements in system development based on the systems engineering process , Master the method of model management.

21. THE UNIVERSITY OF NEW SOUTH WALES / AUSTRALIA

21.1. CERTIFICATE MOOC: INTRODUCTION TO SYSTEMS ENGINEERING

21.1.1. KEYWORDS

- Requirements elicitation
- Conceptual design

21.1.2. COURSE OUTLINE

- Support: Textbook "Systems Engineering Practice"
- Besides mid-course exams and the finals exams, each week there are marked exercises.
- Week 1: Course Welcome & Module 1 (Introduction to Systems and System Life Cycle)
  - Introduction video : overview of the course syllabus
  - Nature of systems and concept of a system life cycle
  - Broad phases and activities of a system life cycle :
    - early identification of the need for the system
    - exploration of options
    - functional design, physical design
    - detailed design and development
    - construction and production
    - utilization and support
    - retirement
    - Marked exercices
- Week 2: Systems Engineering and its Relevance and Benefits
  - Definition of ‘systems engineering’
  - framework within which we can consider the major processes, activities, and artefacts throughout the remainder of the course
  - Relevance and benefits of systems engineering
- Week 3: Needs and Requirements
  - Needs and requirements views developed by business management, business operations, and systems designers
  - Set of requirements—we call that process ‘requirements engineering’
- Week 4: Requirements Elicitation and Elaboration
  - Elaboration: Requirements engineering and processes by which requirements are elicited and defined (which involves derivation and decomposition of lower-level requirements from their parent requirements)
  - Simple requirements engineering tools
  - Notion of traceability
- Week 5: Conceptual Design
  - Conceptual Design: what the system needs to do, how well it needs to perform, and what other systems it needs to interact with in order to meet the stakeholder and business needs and requirements
  - Concept of system level synthesis where we make some high-level design decisions
  - Reviewing our work in preparation of the core design effort normally associated with preliminary and detailed design.
- Week 6: Preliminary and Detailed Design

- Preliminary design: identifying the various subsystems that will need to come together to form our system (What do these subsystems need to be able to do? How do they need to inter-relate? Can we source these subsystems off the shelf or do they need to be designed from the ground up?)
  - Detailed design process and tools like prototyping and how these tools help to refine the detailed design
- Week 7: Construction, Production, and Utilisation
  - Construction and production of the system based on the detailed design from the previous stage
  - Critical systems engineering activities such as configuration audits and system verification
  - Utilisation phase where we explore how systems engineering may continue to be involved via modification and upgrade projects
  - Issues we face when trying to dispose of or retire systems that are no longer required
- Week 8: Systems Engineering Management
  - Key management issues: verification and validation management, configuration management, technical risk management and the management of the technical review and audit program
  - Broad strategies: incremental and evolutionary development
  - Importance of planning throughout the systems engineering program and the development of a governing plan known as the systems engineering management plan or SEMP
- Week 9: Final Exam and Information About Further Study

21.2. UNSW CANBERRA CERTIFICATE OF COMPLETION/ATTENDANCE: SYSTEMS ENGINEERING

21.2.1. KEYWORDS

- Subsystem requirements analysis
- Requirements allocation
- Systems tests and evaluation
- Conceptual design
- Project management

21.2.2. COURSE OUTLINE

- Systems Engineering Processes Introduction
  - History and definitions | Systems life cycle | Benefits and relevance of systems engineering | Systems engineering context | Systems engineering process | Analysis - synthesis - evaluation | Systems engineering framework
- Conceptual Design
  - Business Needs and Requirements | Stakeholder Needs and Requirements | Feasibility analysis | Requirements analysis | Synthesis and evaluation | Systems Specification | Conceptual Design Review | Technical performance measures
- Preliminary Design
  - Subsystem requirements analysis | Requirements allocation | Interface identification and design | Synthesis and evaluation | Specifications and baselines | Systems design reviews
- Detailed Design and Development
  - Designing & integrating elements | Prototype development | Design reviews | Documentation
- Construction and/or Production
- Operational Use and Systems Support
- Retirement
- Systems Engineering Management

- Technical reviews and audits | Systems test and evaluation | Specifications and standards | Technical risk management | Configuration management | Integration management | Engineering management plan
- Related Disciplines
  - Project management | Quality assurance | Integrated logistic support (ILS) | Operators | Other engineering disciplines including software engineering

21.3. UNSW CANBERRA CERTIFICATE OF COMPLETION/ATTENDANCE: SYSTEMS ENGINEERING PRACTICE

21.3.1. KEYWORDS

- (Subsystem) Requirements analysis
- Requirements allocation
- Systems tests and evaluation
- Conceptual design
- Project management

21.3.2. COURSE OUTLINE

- Systems Engineering Processes Introduction
  - History and definitions | Systems life cycle | Benefits and relevance of systems engineering | Systems engineering context | Systems engineering process | Analysis - synthesis - evaluation | Systems engineering framework
- Conceptual Design
  - Business Needs and Requirements | Stakeholder Needs and Requirements | Feasibility analysis | Requirements analysis | Synthesis and evaluation | Systems Specification | Conceptual Design Review | Technical performance measures
- Preliminary Design
  - Subsystem requirements analysis | Requirements allocation | Interface identification and design | Synthesis and evaluation | Specifications and baselines | Systems design reviews
- Detailed Design and Development
  - Designing & integrating elements | Prototype development | Design reviews | Documentation
- Construction and/or Production
- Operational Use and Systems Support
- Retirement
- Systems Engineering Management
  - Technical reviews and audits | Systems test and evaluation | Specifications and standards | Technical risk management | Configuration management | Integration management | Engineering management plan
- Related Disciplines
  - Project management | Quality assurance | Integrated logistic support (ILS) | Operators | Other engineering disciplines including software engineering

21.4. UNDERGRADUATE : INTRODUCTION TO ENGINEERING DESIGN AND INNOVATION

21.4.1. KEYWORDS

- Engineering design

21.4.2. COURSE OUTLINE

- In this course, students will experience first-hand one of the major things that engineers do: designing and building creative solutions to problems. They will learn to think the way that engineers think, coming up with good solutions to problems despite being limited by budget, time and resources, the requirement to also meet environmental and social objectives and of course the limitations of the laws of physics. This will help them to appreciate the central ideas of engineering design as an on-time, on-budget and fit for purpose solution to a poorly specified, open-ended problem.

21.5. MASTER OF SYSTEMS ENGINEERING

21.5.1. KEYWORDS

- Reliability engineering fundamentals
- Requirements practice
- System safety
- Systems thinking and modelling
- Model-based engineering
- Logistics management
- Project management

21.5.2. COURSE OUTLINE

- Core
    - Systems Engineering Practice
    - Requirements Practice
    - Test and Evaluation (4 days)
    - Systems Thinking and Modelling (5 days)
- General Electives
    - Logistics Management
    - Software Project Management
    - System Safety
    - Project Administration
    - Project Management Body of Knowledge
    - Capability Option Analysis
- Electronic Warfare Stream Electives
    - Cyber Operations Not Offered
    - Cyber Defence
    - Info Assurance Principles
    - Information Operations
    - Non-Communications Electronic Warfare
- Networking Stream Electives
    - Cyber Operations Not Offered
    - Intrusion Analysis & Response

    - Network Security Operations
    - Internetworking
    - Satellite Communications
- Space Systems Stream Electives
    - Space Operations
    - Global Navigation Satellite Systems
    - Space Systems Technologies
    - Satellite Communications
    - Spaceborne Imaging Technologies
- Test and Evaluation
    - Advanced Test and Evaluation Techniques
    - Evidence-based Decision Making Distance Mode
    - Decision Analytics
    - Simulation
- Weapons and Ordnance Stream Electives
    - Explosive Ordnance Technologies
    - Weapons Engineering Not Offered
    - Lethality and Survivability
- Reliability Engineering Stream Electives
    - Reliability Engineering Fundamentals
    - Probabilistic Risk Assessment
    - Reliability Engineering Assurance
    - Reliability Program Management
- Marine Engineering Stream Electives
    - Marine Technology*(requires approval)
- Cross Institutional Study: University of Tasmania
    - Modelling & Simulation of Marine Systems
    - Ship Design
    - Design of Marine Machinery Systems
    - More information at UTAS
- Cross Institutional Study: University of Adelaide
    - Intro to Submarine Design
    - Submarine Design
    - Naval Engineering
- Simulation Stream Electives
    - Model Based Systems Engineerin
    - System Dynamics Modelling
    - Simulation
    - Simulation Applications

22. NATIONAL UNIVERSITY OF SINGAPOUR / SINGAPOUR

22.1. MASTER OF SCIENCE (INDUSTRIAL & SYSTEMS ENGINEERING

22.1.1. COURSE OUTLINE

- For whom:
  - graduates with an undergraduate background in a technical field like engineering, science or computing.
  - at least 2 years of practical work experience in planning, designing or managing some aspect of a technical system. They recognize that in order to progress further to the next stage of their career, they would need to acquire knowledge that enables them to deal with the complexity of issues, look at problems in a broader perspective and acquire specific management skills.
  - engineers who develop careers in project management through many years of practice. This programme will help them to consolidate and validate their project management experience through key engineering system concepts and methodology, hence significantly reducing the time to gain expertise compared to their predecessors.

22.2. SYSTEMS ENGINEERING

22.2.1. KEYWORDS

- Designing Systems
- Managing the Systems Engineering Process

22.2.2. COURSE OUTLINE

- AE4S12 Space systems engineering (p 91 of the brochure)
- 1. Introducing Space Systems Engineering
- 2. Designing Systems
  - 2 a. Identifying stakeholder needs
  - 2 b. Generating, evaluating and selecting concepts
  - 2 c. Tutorial I
  - 2 d. From stakeholder expectations to technical system requirements
  - 2 e. Logical decomposition and design solution
  - 2 f. Estimating lifecycle costs
  - 2 g. Managing technical risk
- 3. Integrating Systems
  - 3 a. Integrating the system
  - 3 b. Verifying and validating
  - 3 c. System roll-out & lessons learnt
  - 3 d. Tutorial II
- 4. Managing the Systems Engineering Process
- 5. Managing the technical effort
- 6. Managing interfaces and configuration; Conclusions
- There are four high-level learning objectives:
  - 1. Participants shall be able to explain the objectives and tasks of Systems Engineering for realizing successful systems together with their needs, potentials, benefits and limitations in a context which comprises Business Engineering and Management.

- 2. Participants shall be able to use Systems Engineering methods and tools to solve practical real-world problems when engineering a space system.
- 3. Participants shall be able to design an end-to-end Systems Engineering process demonstrating a smart balance of risks of cost, schedule, and performance.
- 4. Participants shall be able to analyze Systems Engineering topics."

23. VOLET “FORMATION ET ENSEIGNEMENT” DE LA CHAIRE CASAC

Volet formation :

Deux axes sont développés:

1) La mise en place d'une sensibilisation sur la notion d'« architecte de systèmes aériens » en s'appuyant principalement sur l'existant du cursus ingénieur de l'ISAE-SUPAERO :
   - Le module de 2e année associé à l'avant projet avion
   - Un parcours expert s'appuyant sur :
     - des modules d'enseignement électifs en 1A, 2A
     - le domaine Conception et Opération des Aéronefs
     - le certificat en ingénierie système
   - Des projets recherche et des projets ingénierie, ciblé sur des cas concrets rencontrés dans le monde industriel
   - Des stages, césure, PFE chez DASSAULT AVIATION ou labo ISAE-SUPAERO
   - Un semestre ou année complémentaire à l'étranger (réseau ISAE-SUPAERO / DASSAULT AVIATION)
2) Conduite d'une réflexion sur les formations d'architecte de systèmes aériens en formation initiale et formation continue
   - Analyse des besoins et attentes des industriels - Pilote DASSAULT AVIATION
   - Benchmarking des formations existantes au niveau national et international - Pilote ISAE-SUPAERO
   - Bilan des formations proposées à l'ISAE-SUPAERO et proposition d'évolution si besoin

24. RESUME FOURNI PAR LE JUNIOR ENTREPRISE

lao.willy@gmail.com

Willy LAO
Benchmark Systems engineering

M. Vingerhoeds
Mme Mansuet

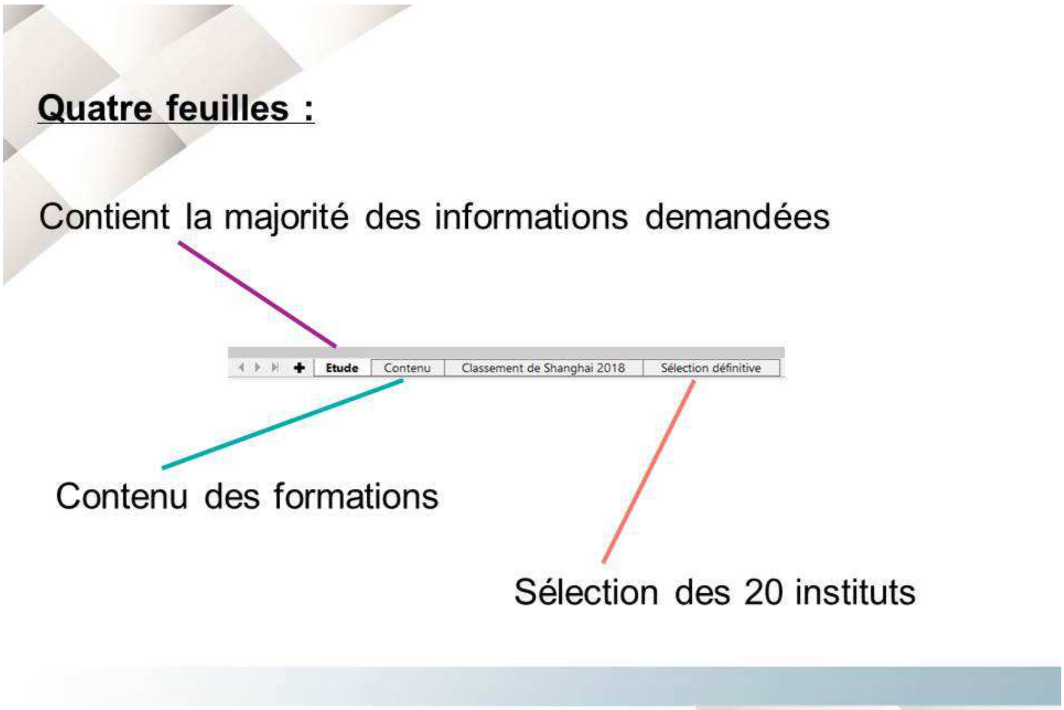
Institut Supérieur de l'Aéronautique et de l'Espace
SUPAERO

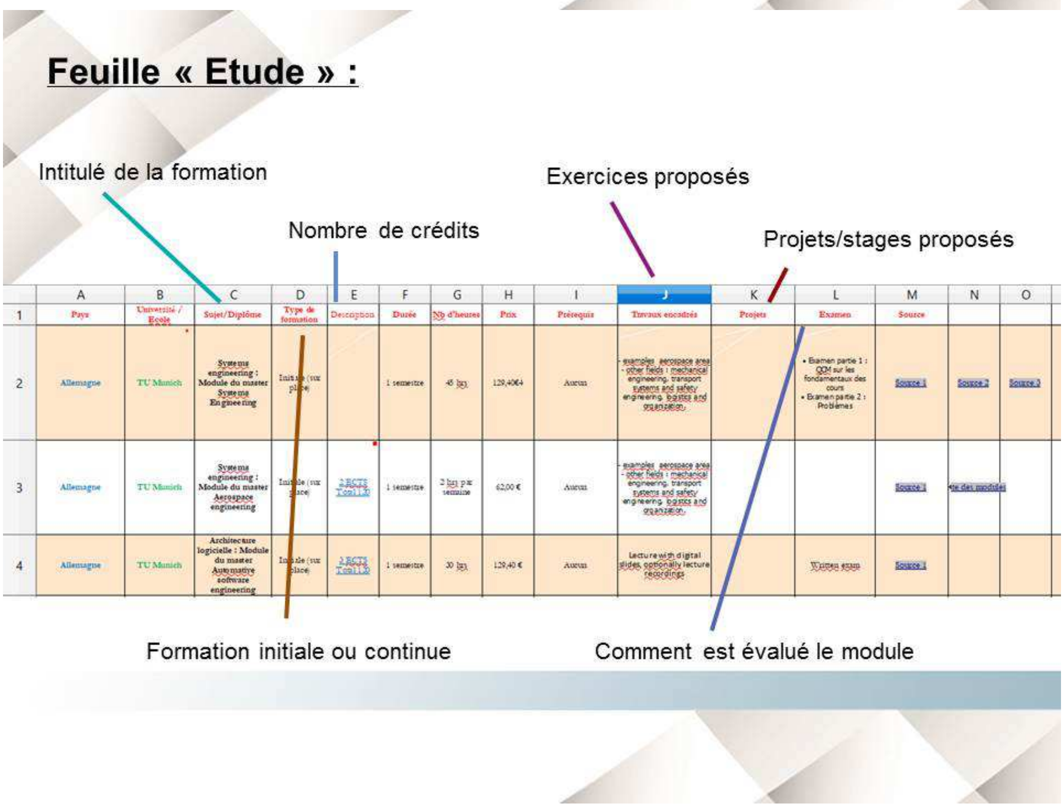
Résultat final
- 20 instituts audités
- 12 pays différents
- 133 formations en systems engineering
  → dont 8 formations continues

Livrables :
- Powerpoint de présentation des résultats
- Tableau contenant 4 feuilles

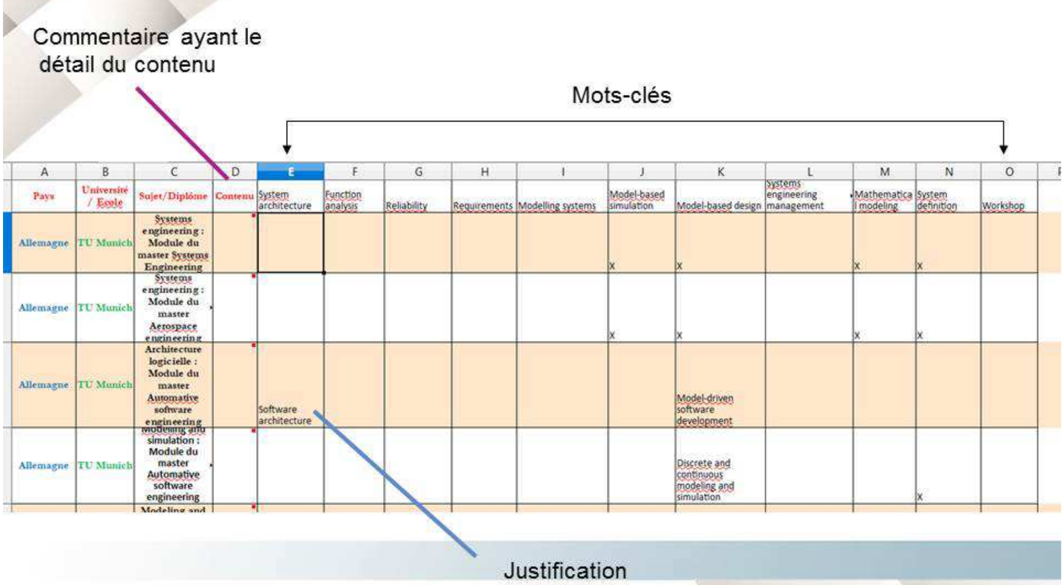
→ Etude → Classement de Shanghaï
→ Contenu → Sélection définitive

Temps estimé au préalable : 35h
Temps réel passé sur le projet : 85h


Quatre feuilles :
Contient la majorité des informations demandées
Etude
Contenu
Classement de Shanghai 2018
Sélection définitive
Contenu des formations
Sélection des 20 instituts


Feuille « Etude » :
Intitulé de la formation
Exercices proposés
Nombre de crédits
Projets/stages proposés
Formation initiale ou continue
Comment est évalué le module

Feuille « Contenu »



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Pays	Université / Ecole	Sujet/Diplôme	Contenu	System architecture	Function analysis	Reliability	Requirements	Modelling systems	Model-based simulation	Model-based design	Systems engineering management	Mathematical modeling	System definition	Workshop
Allemagne	TU Munich	Systems engineering : Module du master Systems Engineering							x	x		x	x	
Allemagne	TU Munich	Systems engineering : Module du master Aerospace engineering							x	x		x	x	
Allemagne	TU Munich	Architecture logicielle : Module du master Automative software engineering		Software architecture						Model-driven software development				
Allemagne	TU Munich	Modeling and simulation : Module du master Automative software engineering								Discrete and continuous modeling and simulation			x	
		Modeling and												

Méthodologie

- Recherche des formations ayant les mots clés mentionnés précedemment
  → Site internet : Master courses/PhD/undergraduate
- Rassemblement des données
- Filtrage et synthèse
- Recherche des points communs entre les formations
- Mise en forme

Commentaires :
- Exhaustivité dans les formations repérées
→ Parfois des doutes si la formation est bien du systems engineering
→ Je me suis alors fié aux mots-clés

- Exhaustivité dans les informations récoltées
→ J'estime avoir récolté 90 % des informations interéssantes

- Perte d'information à cause de la synthèse dans les cases
→ Regarder les commentaires ou les sources

Analyses :
- Des formations proposées très différentes
→ Durée : 1 trimestre, 1 semestre, 1 an
→ Domaine varié : electronical engineering, aerospace, data science..
→ Pré-requis différent : aucun ou familiarité avec les mathématiques, sciences, langage de programmation, expérience professionnelle...

- Le prix dépend du pays
→ Parfois très onéreux pour les étudiants internationaux

- Chaque formation propose des TP, workshop ou stages
→ Importance donnée au travail d'équipe, au management de projet

Enrichissement personnel :

- Je suis très intéressé par l'ingénierie système
→ Je compte passer le DESIA l'année prochaine
→ J'essaie de trouver un stage en system engineering

- Le benchmark m'a permis :
→ De mieux connaître ce qu'est le system engineering
→ De connaître ce que proposent les écoles dans le monde entier
→ D'améliorer mon organisation pour les tâches répétitives
→ D'améliorer mon esprit de synthèse
→ D'apprendre à travailler à distance