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MELiSSA

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TECHNICAL NOTE 55.3

Higher Plant Compartment Optimisation and modelling methodology
and
Use of Equivalent System Mass (ESM) models developed for Advanced Life Support Systems for MELiSSA analysis

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Content

I Introduction

The present work comprises two parts, the first are devoted to a first review on higher plants culture models, the second one being centered on ESM methodology analysis for MELiSSA.

1- The statement of works and methodologies for the integration and the definition of the Higher Plant Compartment in the modelling approach of the MELiSSA loop. Higher plants have been introduced in the MELiSSA loop as a food producer for the crew. This approach is quite original compared to the other international Biological Life Support Projects in which Higher plant is the core of the system , supporting most of the function of the Life Support System. The use of plant has been for human life support in space was discussed as early as the 50's. Though the first studies were centred on the algae, there was a shift in the 70's to higher plants. Then numerous studies have been conducted on the higher plant as part of a closed ecological system. These studies deal with technical aspects for the growth of plants in controlled closed chamber, plant selection, plant growth (yields, conditions of culture…)… We will focus the review of these studies on the methods used for the selection criteria of higher plant and on the knowledge for higher plant modelling.

2- The study and the analysis of the Equivalent System Mass methodology used for the evaluation of the Advanced Life Support Systems scenario. The Equivalent System Mass (ESM) is a technique by which several physical quantities which describe a system or a subsystem may be reduced to a single physical parameter : mass. This method was developed and mainly used by the National Aeronautics and Space Administration (NASA) to measure the Advanced Life Support (ALS) Program's progress and to allow comparison of two life support systems with different parameters using a single scale. As current ALS scenario are often compared by their ESM, it would be interesting to develop the same methodology for the MELiSSA loop.

II Higher Plant Compartment optimisation and modelling

II.1 Optimisation of Higher Plants Compartment

II.1.1 Higher plants selection and optimisation

The optimisation of a higher plant compartment is usually limited to the selection of the relevant plants, allowing to meet the crew food constraints with :

- The highest variability of food source and palatability and dietary acceptance by a crew;
- The smallest crop area , which is mainly related to its growth yield, but also depend of its life cycle;
- The easiest cultivation and product processing techniques, including time spent for cultivation and food preparation;
- The best integration in a closed loop, (i.e. small wastes production and the recycling of nutrient required for the growth from crew and other biological wastes);

Nutrient	Units	Requirement
Energy	kilojoules (kilocalories)	WHO[a] equation
Protein	% total energy consumed	12-15
Carbohydrate	% total energy consumed	50-55
Fat	% total energy consumed	30-35
Fluid	ml per MJ consumed or ml per/kcal	238-357 or 1.0-1.5 or at least 2000 ml/d
Vitamin A	µg retinol equivalents	1000
Vitamin D	µg	10
Vitamin E	mg a-tocopherol equivalent	20
Vitamin K	µg	80
Vitamin C	mg	100
Vitamin B_{12}	µg	2
Vitamin B_6	mg	2
Thiamin	mg	1.5
Riboflavin	mg	2
Folate	µg	400
Niacin	mg Niacin equivalents	20
Biotin	µg	100
Pantothenic Acid	mg	5
Calcium	mg	1000-1200
Phosphorus	mg	1000-1200 <1.5 times Ca intake
Magnesium	mg	350
Sodium	mg	1500-3500
Potassium	mg	3500
Iron	mg	10
Copper	mg	1.5-3.0
Manganese	mg	2.0-5.0
Fluoride	mg	4
Zinc	mg	15
Selenium	µg	70
Iodine	µg	150
Chromium	µg	100-200

Table 1 : Daily nutritionnal recomandation for International Space Station missions up to 360 days (Lane and Schoeller, 1999).

When selecting higher plants for closed systems, the most important criterion usually considered is that of satisfying human food requirements. All space agencies have used the nutritional daily needs (carbohydrates, proteins, lipids, minerals, vitamins..) to define these food requirements. Based on past US mission and studies, the daily nutritional recommendation for International Space Station missions up to 360 days are reported in Table 1 (Lane and Schoeller, 1999).

To our knowledge the "optimised Higher Plant Compartments" use these food requirements (mainly carbohydrates, proteins, lipids and energy requirements) as fitting constraints ; Jones (2000) has added to these criteria other minimising criteria (such as the area of the HPC) (TN 32.3, 1997).
An exception are works of Cloutier et al. (2000) and Olabi and Hunter (1999) which use predefined menus and optimise servicing of these menus by minimising a cost criteria.

This last approach of Cloutier et al. (2000) seems more in adequation with the implementation timeline for ALS food system proposed by Lane and Schoeller (2000), reported in Figure 1. With the work of Hentges and Ruminsky (2000) this is one of the rare studies which clearly designs the menus and food prepared with the selected plants growth in the HPC.

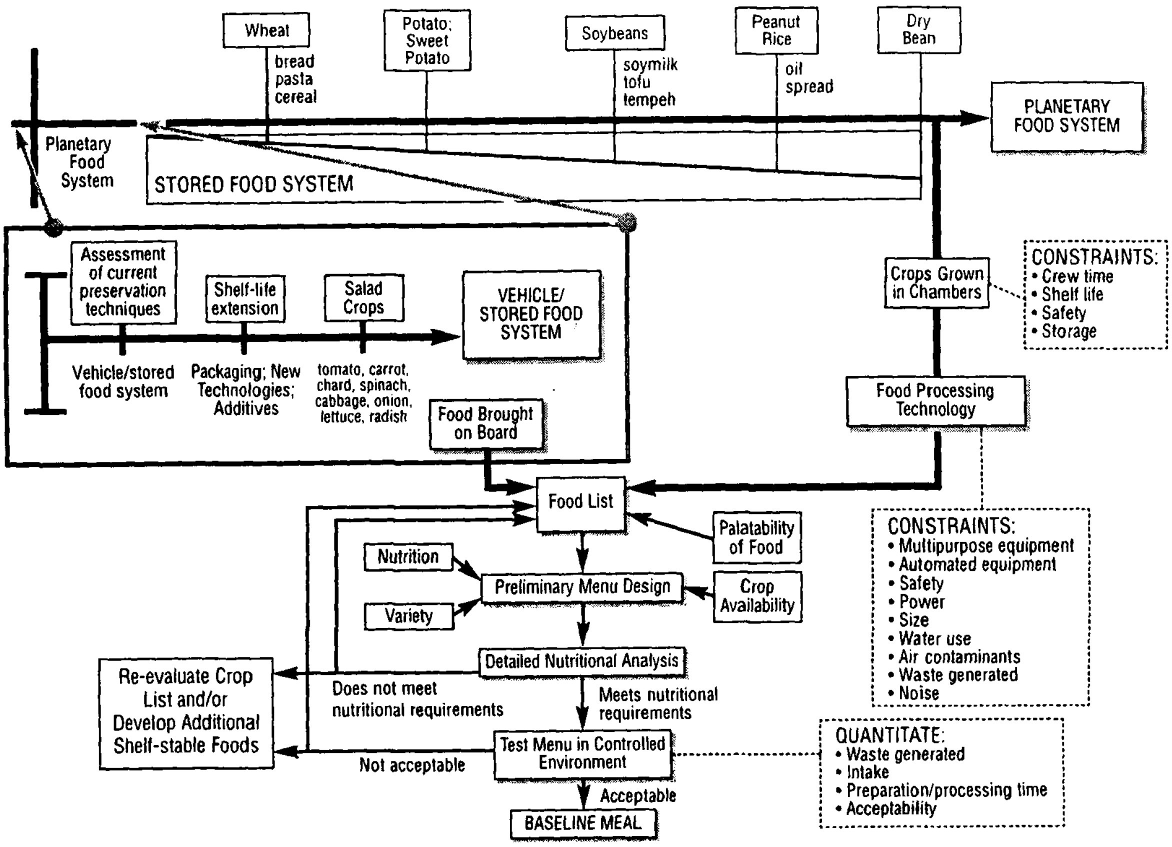


Figure 1 : Implementation timeline for ALS food system (Lane and Schoeller, 1999).

II.1.2 Review of the crop selections and menus

In the numerous theoretical and experimental studies of crop growth in controlled environment, wheat, lettuce, soybean potato and sweetpotato were the crops the most commonly found and the most extensively studied. Other crops often considered are tomato, rice, peanut, radish, spinach, onion. An overview of the crops selected for the use in Life Support Systems are presented in Table 2. In general, the crops were selected for their nutritional value, their palatability and dietary acceptability associated to their high yield potential.

Ref a)	Ref b)	Ref c)	Ref d)	Ref e)	Ref f)	Ref g)	**Ref h)**
Broccoli Lettuce Onion Pea Peanut Potato Rice Soybean Strawberry Sugar Beet Sweetpotato Taro Wheat Winged Bean	Cabbage Carrot Chard Dry Bean Peanut Potato Rice Soybean Tomato Wheat	Broccoli Carrot Chickpea Chili Pepper Kale Lentil Lettuce Onion Peanut Rape Seed (Canola) Rice Soybean Sweetpotato Tomato Wheat	Beet Cabbage Carrot Cucumber Dill Nut Sedge Onion Pea Potato Radish Salad species Tomato Wheat	Cabbage Carrot Chard Dry Bean Lettuce [bx)] Onion Peanut [bx)] Potato [bx)] Radish Rice [bx)] Soybean [bx)] Spinach Sweet Potato [bx)] Tomato [bx)] Wheat [bx)]	Komatsuna Potato Rice Sesame Soba Soybean Tomato	Alfalfa Bean Beet Broccoli Cabbage Carrot Cauliflower Chili Peppers Cucumber Green Onion Herbs Kale Lettuce Mushrooms Onion Peanut Peppers Potato Rice Snow Peas Soybean Spinach Squash Sweet Potato Swiss Chard Tomato Wheat	**Lettuce** **Onion** **Potato** **Rice** **Soybean** **Spinach** **Tomato** **Wheat**

Table 2 : Possible crops for use in Life Support Systems.

a) Tibbits and Alford (1982). Controlled ecological Life Support Systems. Use of Higher plants. NASA CP-2231. NASA. Washington, D.C. From Lane and Schoeller (1999)
b) Hoff, Howe and Mitchell (1982). Nutritional and cultural aspect of plant species selection for regenerative life support system. Report to NASA Ames research Center, NSG2401 and NSG 2404. From Lane and Schoeller (1999)
c) Salisbury and Clark (1996) Choosing plants to be grown in a controlled environment life support system based upon attractive vegetarian diets. Life Sup. Biosphere Sci. 2 : 169-179. From Lane and Schoeller (1999)
d) Gitelson J.I. (1999).
e) Jones H. (2000). These are the 15 crops identified as baseline for ALS programs by NASA. [bx)] crop have been used in Bio-Plex HPC design.
f) Toki et al. (1994)
g) Cloutier et al. (2000)
h) Poughon et al. (1997)

The food and menu proposed with the crop selected are not extensively described.

In BIOS 3, lyophilised and canned products in ready and prefabricated forms were used together with the vegetable cultivated (Table 2), affording 4 diversified meals a day and a 5 days menu cycle. If the stored products were rationed, the use of the phytotron produce was within the crew discretion, depending on the amount and assortment available which are not the same at all time because of the crop life cycle. One interesting result that can be obtained from the BIOS 3 experiment concerns the crew time requirement for crop cultivation (2.11 to 4.6 h/man.day) and food production/processing (1.7 to 3.8 h/man.day)

An approach associating foods/menus and crop selection was described by Cloutier et al. (2000). Though, in this approach foods, menus and menus cycles are more detailed, it is important to notice that it entails a huge number of crops (Table 2) compared to the other higher plants based scenarii. But this approach seems more realistic on a menu and diet point of view. The food selected by Cloutier et al. (2000) are reported in appendix A.

In a similar way Hentges and Ruminsky (2000) present an analysis of a 10 days cycle menu in Bio-Plex using the 15 crop reported in Table 2. With these crops 66 recipes were obtained (21 entrees, 13 side dishes, 3 soups, 5 breads, 9 salads, 12 desserts and 3 condiments) (Appendix B). It can be outlined that Hentges and Ruminsky don't optimise the Higher plant Compartment, giving only the crop production requirement and checking the nutritional covering of the menus. The size of the Higher plant compartment is not calculated and the average calories calculated from the menus is 1850 kcal/day.man, what is low compared to the average of 3000 kcal/day.man usually assumed for space missions (Jones, 2000 ; TN 32.3).

II.1.3 Higher plants chambers design for the higher plants selected

An overview of the projects and studies concerning HPC based Advanced Life Support Systems was given in TN 32.3.

Most of applied studies of crops in controlled closed chambers concern plant physiology (plant requirement, plant yield and harvest index) and horticultural and processing requirements. These knowledge are important not only for the design of a single plant growth chamber but also for the design of biomass production units (BPU) including more than one crop (comparable growth cultivation conditions such as photoperiod, humidity….). For the MELiSSA selected crop, these points are extensively detailed in TN 40.1 (Cloutier and Dixon, 1997). The use of multiple BPU (or BPC) has a penalties in terms of mass and volume, even if values for these penalties are not detailed in literature.

The requirements and the compatibility of the growth of several plants in the same BPU influence the design of the HPC. Then it is probably an important element to take also into account in the optimisation of the HPC. This point does not seem to have been actually taken into account in the current and past BLSS studies (theoretical studies and testbeds).

In BIOS3, two hermetically phytotrons occupying about half of the volume of the complex were used. Each phytotron were more closed room than controlled chambers and contains 2 plant cultivating systems, one illumination system, a heat removal system. They consist in 12 identical trays (measuring 140x100x12 cm). In the 20.5 m^2 of each phytotron 17 m^2 were for wheat and 3.5 for the other crop (Table 2) (Gitelson and Mac Elroy, 1999). The 41 m^2 cultivated were used for long-term ground based experiment with crew of 3 and 2 men, producing less than 40% of the food needs. An experiment in BIOS 3 with a third phytotron, offering a cultivated area of 63 m^2 and with a crop distribution optimised for the nutritional requirement of the crew of 2 men, was also performed during 5 months. This last system covered 70 to 80% of the food requirement.

The current Bio-Plex project can be compared to the BIOS3 experiment. It involves 2 Biomass Production Chambers of 82.5 m^2. Each BPC is divided into 10 shelf of various size for the cultivation of one kind of crop. With the two BPCs it is hoped to provide 95% of the caloric requirement of a crew of (Jones, 2000).

It can be seen that the areas estimated for covering the needs of one man are comparable, about 42 m^2/man in Bio-Plex, about 32 m^2/man in BIOS3, 31 m^2/man in MELiSSA (Poughon et al., 2000) or 18 m^2/man (Drysdale, 1994), depending on the number of plants used and the productivity value used. It is also interesting to noticed that for BIOS3 and Bio-Plex testbed projects, the crop distribution was based only of caloric and macronutriment constraints (see II.1.4.1).

Another point which not often directly considered in design of Higher Plant Chamber, even if it is cited, is the life cycle of plants and their consequences in term of storage (Hentges, 2000) and tray or shelf with various age group of plants (Gitelson, 1999). As an example, Gitelson (1999) reports the following age structure for the conveyers for the wheat cultivation in BIOS 3:

	Area	Growth period	Conveyer stage duration	Number of conveyers age group
Wheat	17.5 m^2 (44% of total area)	63 days	9 days	7

This configuration allow an harvest of wheat every 9 days.
The number of age group influence also the dynamics of the Higher Plant Chamber (see II.2) (Gitelson and Mac Elroy, 1999).

II.1.4 Proposed methodology for higher plant selection and optimisation for the MELiSSA loop

In previous parts, a short review of crop selected for Higher Plant Compartments and of the critical points to take into account in cultivation and design of HPC was presented. As previously mentioned, some projects (theoretical and testbed) have investigated the design of the Higher Plant Compartment by optimising the crop cultivated. Principles of the main methods used will be described here and principle for a strategy for optimising the Higher Plant Compartment in the MELiSSA loop will be proposed.

II.1.4.1 Analysis of existing optimisation

The methods used for optimisation are based upon the minimisation of a criteria value, in respect with possible other constraints. Generally, the procedures involve the resolution of a set of linear equations.
Two main optimisations (or selection criteria methods) can be found in the literature.

“Nutritional based” method
This is the most intensively used (Figure 2) optimisation method. The objectives are usually the distribution of a pre-selected set of plants for designing a Higher Plant Compartment with the lowest area (i.e. minimisation criteria), the cultivation area being directly linked to the mass of the system (Jones, 2000), and with the best fit of nutritional and caloric requirements of the crew.

It is important to notice that nutritional requirements mean carbohydrate, lipids, proteins, and sometimes vitamins and minerals proportion, but don’t deal with the foods, menu and menu cycles. Then the results obtained with this optimisation method can mismatch the crop production that are required for the definition of foods and menus, as it is illustrated in Table 3 for 2 different Bio-Plex studies.

	Nominal productivity	Bio-Plex with 1 BPC a)		Bio-Plex with 2 BPC a)		10 days menu requirements b)
	Edible g/m2.day	Area (m^2)	Edible g/day production	area (m^2)	Edible g/day production	g/day for a crew of 4
wheat	*17.7*	20.8	368.16	47.8	846.06	385.16
potato	*19.5*	6.2	120.9	47.4	924.3	418.99
peanut	*9*	0	0	69.6	626.4	115.284
soybean	*5.7*	42.6	242.82	0	0	939.91
lettuce	*5.8*	3.3	19.14	0	0	29.99
tomato	*17*	3.3	56.1	0	0	1238.33
sweet potato	*12*	6.2	74.4	0	0	307.32
other crops	-	-	-	-	-	666.88
Sum		**82.4**	**881.52**	**164.8**	**2396.76**	**3434.98**
						Sum including other crops and ressuply)
						4275.78

Table 3 : Comparison of optimisation of Jones (2000) for Bio-Plex BPCs and Hentges (2000) menu design for Bio-Plex
a) from Jones (2000). Values are given in dry edible mass.
b) from Ruminsky and Hentges (2000). Values seems given as edible wet g/day (?).

This method for the design of HPC was used for Bio-Plex and the 5 months-2 men crew experiment of BIOS-3. It can be noticed that in Bio-Plex the BPC are already defined as 10 shelf of 14.2, 6.2 or 3.3 m^2 (Jones, 2000) and then optimisation performed by Jones is a combinatory distribution of crops in the shelf.

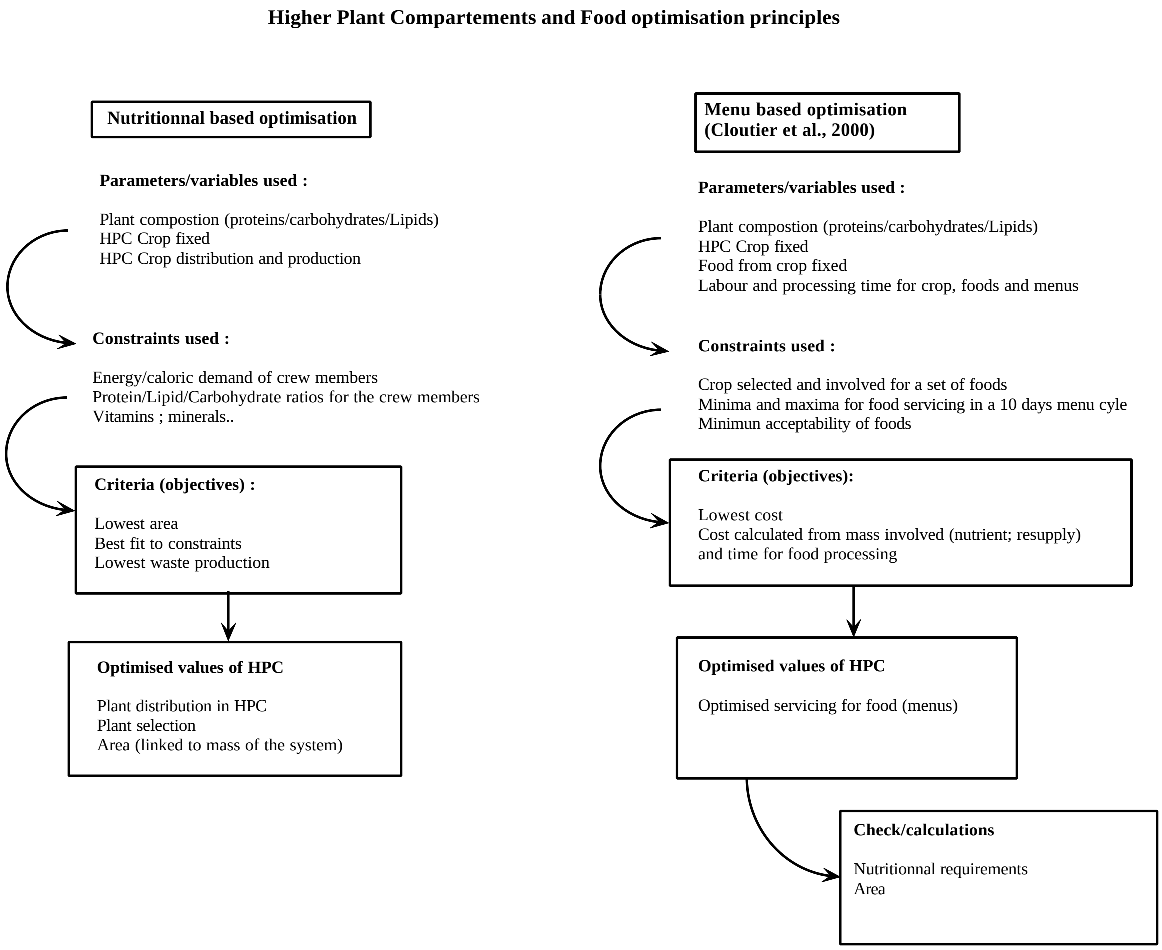


Figure 2 : principles of the two mains methods used in HPC optimisation

"Menu based" optimisation

To our knowledge, this method was only used by Cloutier et al. (2000). The work of Ruminsky and Hentges (2000) are also based on the study of Higher Plants Compartment (for Bio-Plex), but is not an optimisation. It is only the calculation of the crop production in a HPC to match the fixed menu cycle.

In the "menu based" studies, menu are defined from a pre-defined set of crop which allow to make a set of foods. Foods are then further used to define menus (with optimised servicing in the work of Cloutier et al. , 2000). Acceptability of foods and menus are tested (and are also one of the constraints in the optimisation by Cloutier et al.) and nutritional requirements matching are checked.

The principles of the "menu based" optimisation is detailed in Figure 2. In the optimisation proposed by Cloutier et al., the minimisation criteria is a cost factor taking into account mass and time for crop and food processing, and the variable to minimise the cost criteria is the servicing of each food (i.e. the menus compostion).

It must be noticed that the menu always involved a set of crop greater than those used in "nutritional based" optimisation. The optimised HPC of Cloutier et al. (2000) give an area of about 75.5 m^2/man and a food closure of 94%. The 10 days menu of Ruminsky and Hentges

(2000) gives a food closure of about 95% and we have estimated the HPC area to about 60-70m^2/man. The area of "menu optimised" HPC would be higher than those "nutritional based" ones, mainly due to the increase in the number of crop.

II.1.4.2 Proposals

On our point of view, the "nutritional based" optimisation is good point for starting the design of a HPC, but as is was illustrated for the Bio-Plex studies, **it can not be used for the design of a real menu cycle**. Then if the HPC is defined as the food producer of the BLSS for long term missions, the food and the menu aspects must be taken into account, and then a "menu based" optimisation must be used.
It must be noticed that if in the scenario chosen the HPC is not the main food producer (HPC producing 30% of the food for example) the strategy for the optimisation can be different (choice of a reduced set of crops; set of several food to be produced). As an example, if we limit the HPC to wheat for bread production, an area of 15 m^2 is sufficient for covering the carbohydrates needs of one man, and also the oxygen requirements.

In any cases, the optimisation can not be made without the knowledge of the crop that we intend to use. We suggest the building of a "spreadsheet data base" for the MELiSSA project, compiling all the required informations for the crop and the HPC. A first compilation of data reported by Cloutier et al. (2000), in TN 40.1 and 32.3 can be initiated. This knowledge must cover the :

- Cultivation aspect of each crop (labour, photoperiods ; life cycle ; temperature …..). This will enable to identify crop that can be grown together (work of TN 40.1 can be re-used), to choice the age rotation….
- Mass balance aspect. This point is related to the stoichiometric equation modelling (see next paragraph).
- Nutritional aspect (composition).
- Which food can be obtained from one crop (or a set of crop), which quantities of crop are required (constraint for the crop production), what is the processing time from crop to food.
- The acceptability of the food
- The servicing that can be admitted (constraints for the menu design), and the quantities of food admitted in one servicing
- The processing time from food to menu (cooking)

The last point to face is the system of constraints and criteria that have to be considered in the optimisation. The choice can be different for each chosen scenario.
Then constraints can be the number of Biomass Production Unit, the tray area (as presented for Bio-Plex optimisation by Jones, 2000), the caloric needs for the crew….
The minimising criteria must be a cost factor which can be simple (equal to the waste produced) or more complex as that described by Cloutier et al. (2000), including time for crop and food processing, mass of the system (this is an Equivalent System Mass approach).

An Excel® template spreadsheet is proposed which include the 3 steps procedure previously detailed and reported in Figure 3. The Solver of Excel® can be used to solve the problem of minimising a criteria with respect of several constraint.
This approach would be useful within the MELiSSA partners as it can be a common basis for various studies theme (nutritional ; Chamber design ; scenario choice….).

A similar approach is described by Hsian et al.(2000) for the top modelling of food processing and nutrition (FP&N) component of ALSS. The authors proposed also an evolution of the Excel analysis to an object-oriented modelling with separated structure and class objects for nutritional (or crew) , food processing biomass production unit (i.e. HPC) aspects. These "top level" models are currently developed at NJ-NSCORT (New Jersey – NASA Specialized Center of Research and Training) (Rutgers University). They seem not used as optimising tools for biomass production chamber but as analytic tools for ALSS.

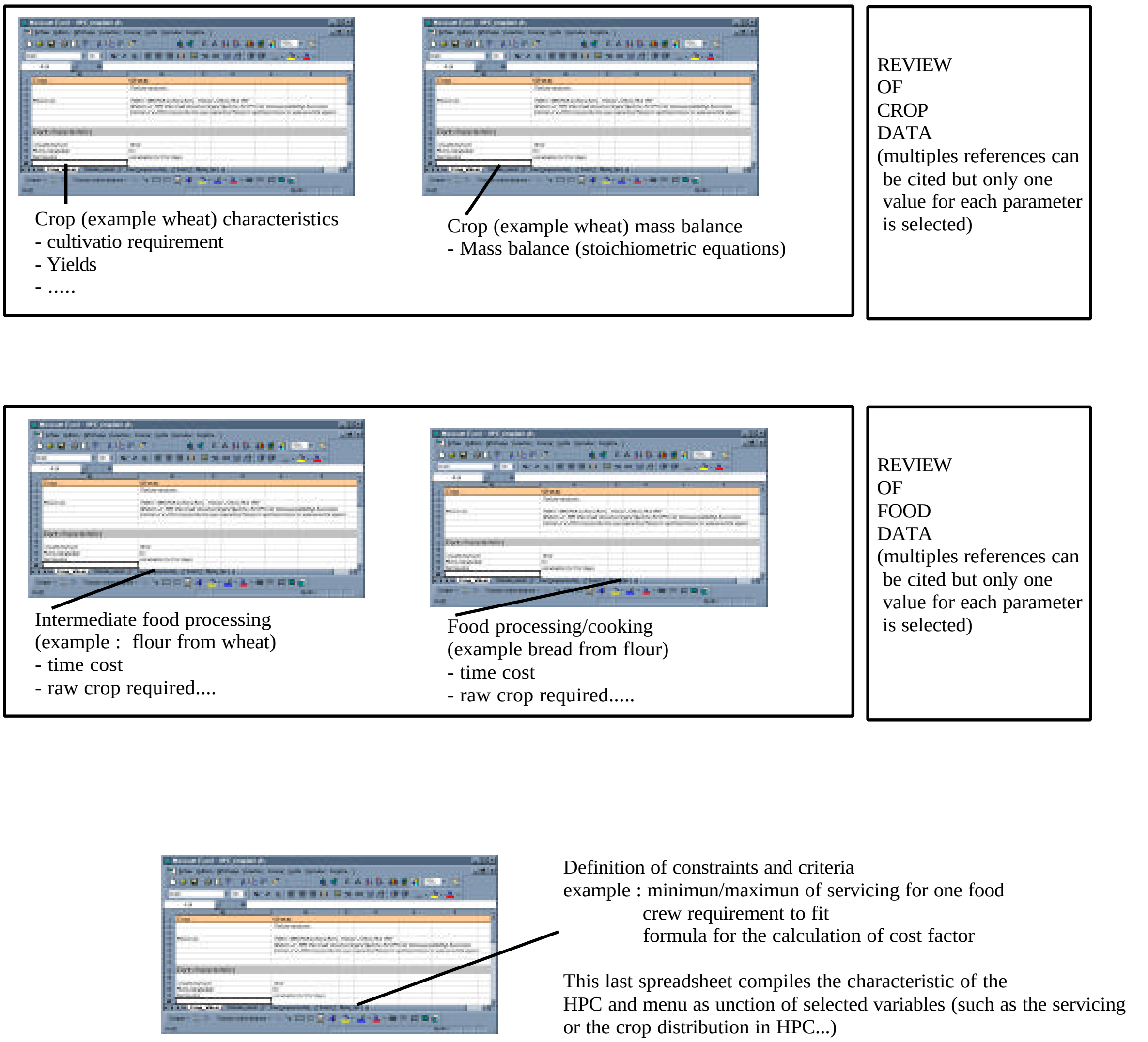


Figure 3 : Proposed strategy for an Excel® template compiling data for an HPC and its optimisation. Report also to appendix D for more details.

II.2 Modelling Higher Plants Compartment

The modelling of Higher Plants is a part of the overall strategy of the MELiSSA which is based upon the predictive control of the loop and of its subsystems. If predictive models can be proposed for unicellular organisms (cyanobacteria, bacteria) and controlled species, such models are more difficult to build for multi-cellular organisms or complex processes (such as multi-species processes). Consequently, it is also more difficult to control complex organisms and complex processes.

The modelling approach used in MELiSSA (as well for each processes and for the loop itself) is first a mass balance modelling and followed by a dynamic modelling.

II.2.1 Mass balance models

A mass balance modelling for the 8 crops currently selected for the MELiSSA loop (Table 2) was made in TN 32.3.
For each crop a mass balanced equation is written in the following form :

$$CO_2 + NH_3 + HNO_3 + H_2SO_4 + H_2O$$
$$\Downarrow$$
$$O_2 + [CHONS]_{digestible} + [CHONS]_{fibre} + [CHONS]_{waste}$$

where digestible and fibres are the edible part (consumed) part of the crop, and waste the non edible part of the crop.

The detailed composition of plants and the stoichiometric coefficients can be found in TN32.3. It must be noticed that the mass balanced equations so far derived were based upon mean compositions of harvested plants, with a set of assumptions concerning the non edible part chemical composition (TN 32.3). The whole life cycle of the crop is represented by a single mass balance equation, then variation in growth yields and crop composition during the life cycle (vegetative growth, reproductive phase, flowering….) are not considered.

To our knowledge, there is no detailed mass balance analysis available for each step of the life cycle of a higher plant. Therefore susch a work remains to be done for HPC MELiSSA compartment in order to match the methodology so far applied to the other compartments of the system.

II.2.2 Dynamic models / Growth models of plants

From Cavazzoni J. (NJ-NSCORT), there is 3 kinds of crop models :

- Descriptive models, reflecting little details of the underlying mechanisms of the plant;
- Explanatory models on which plant processes are quantified and integrated to calculate daily growth and development;
- Top level models that lie between the two approaches in complexity.

Crop models have been intensively developed for agricultural and ecological purposes. The large number and variety of models cannot be fully described here, but an overview of them can be found on the network server for Ecological modelling (http://dino.wiz.uni-kassel.de/ecobas.html). A short review of crops models can also be found in appendix C.

These models cannot be used directly for controlled environment and ALS studies. They must be modified. Fleish et al. (1999) have used modified CERES, CROPGRO and SUBSTOR models for the hydroponic and controlled environment production in Bio-Plex.

Whatever is the model used, and the parameters involved, a consensus can be observed in the models presented for plants in controlled environment (Gitelson, 1999; Jones and Cavazzoni, 2000 ; Cloutier and Dixon., 2000) :

- For a constant Photosynthetic Photon Flux (PPF), the net photosynthesis (Pn), the gross photosynthesis (Pg) and the respiration (R) are proportional to the canopy PPF absorption, the canopy quantum yield and the yield of carbon fixed by PPF absorbed (usually assumed to be constant). The net CO_2 fixation is also directly proportional to Pn, Pg and R and photosynthetic rate can be expressed as CO_2 fixed/time unit.

- The time profiles of all crop for the a net photosynthesis (Pn), the gross photosynthesis (Pg) and the respiration (R) have a common shape (Figure 4).

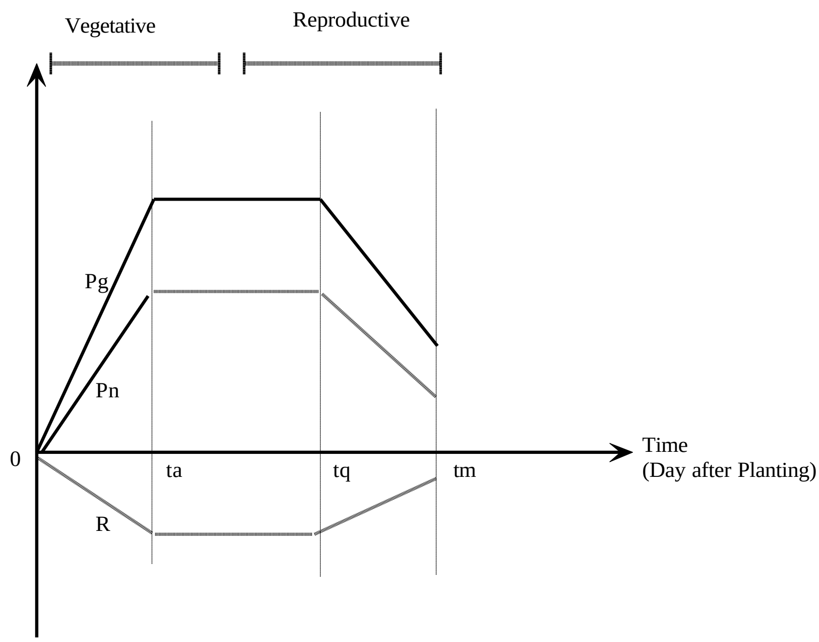


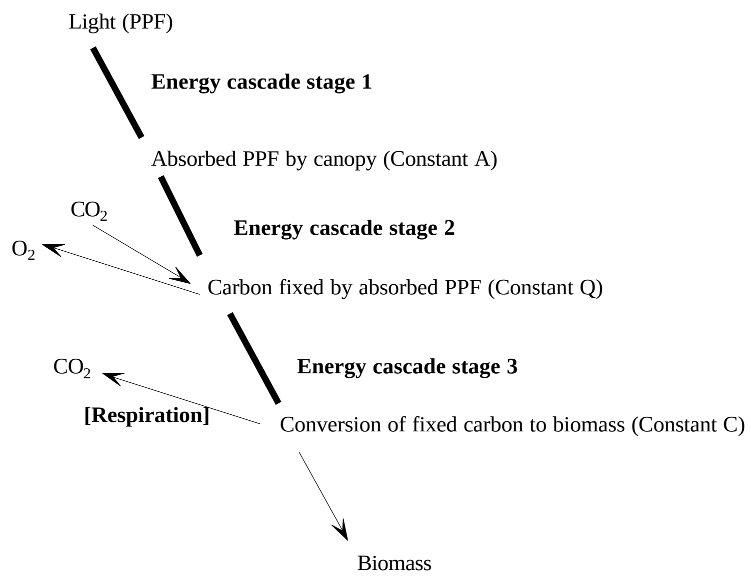
Figure 4 : **"Straight Lines"** time profile of Pg, Pn and R. [ta: time for canopy closure ; tq : time for senescence or grain setting ; tm : time of maturity or harvest].
Note that real profiles are smoother in fact than the set of 3 straight lines.

- The carbon fixation and the growth of the different parts of the plant (redistribution of the carbon fixed) depends directly of the photosynthetic rates.

Then, in other words, the dynamic model for a plant can be reduced to its photosynthetic rates, and more generally represented by its CO_2 fixation rate. The growth rate of edible and non edible part of the plant being further calculated from this fixation rate.

Nevertheless it can be noticed that in ECOSIM (Schramm, 1994) the lettuce growth was described directly by a logistic law (valid only for the first part of the plant growth, i.e. vegetative life cycle).

The **“<u>top-level models</u>”** of Jones and Cavazzoni (2000) are predictive models based upon “energy cascade models”. The principle of these “top level models” is detailed in figure 5. They were used to simulate crop growth and carbon dioxide use in Bio-Plex BPC for various environmental conditions. Giving “straight line profiles” for plants (Figure 4) they are relatively simple to solve numerically.



Pg = A.Q.PPF (light period)
Pg = 0 (dark period)

Pn = Pg-R
Pn = C.A.Q.PPF (light period)
Pn = (C-1).A.Q.PPF (dark period)

R=(1-C).A.Q.PPF (equal in dark and light periods)

Figure 5 : Principle of the top level models (energy cascade models)

The **“<u>explanatory models</u>”** are based upon polynomial and non linear parametric relations. Cloutier and Dixon (TN 40.3) have presented the two main models used :

Rectangular hyperbola model : $Pn = \frac{a.I.P_{g.\max}}{a.I + P_{g.\max}} + R_d$

Exponential model : $Pn = P_{n\max}[1 - e^{-\frac{a.I}{P\max}}]$

[Note : during the growth, the maximum photon flux density being a function of time]

They are more complex than the “top-level models” and therefore give smoother profiles for photosynthetic rates. The explanatory crop models of the DSSAT software (Decision Support System for Agrotechnology Transfer) have been modified at NJ-NSCORT for ALSS crop modelling. Changes concern cultivation differences (from open field to hydroponics), calibration of genetic change in the plant used, models for the light absorption in photosynthesis and effect of CO_2 concentration on growth rate. The results obtained with these modified models suggest that they can be used for the ALSS crops (Fleisher et al., 2000) (Figure 6). We don’t have studied the structure and the bases of these models, but they are probably complex as the authors develops Multivariate Polynomial Regression models to simplify them and to utilise them with a control system.

These models based on non-linear parametric approach are subject to instability and Cloutier and Dixon (2000) proposed a non-linear non parametric approach for modelling the photosynthetic rate. If the non parametric models are more advantageous for the description of complicated growth trajectories, such as those of plants, it is still necessary to know how to integrate such models in a predictive and control strategy.

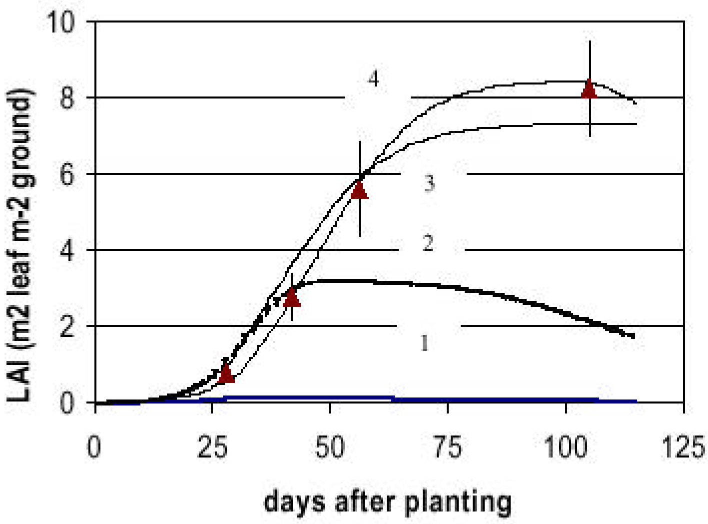


Figure 6 : Results of the modified SUBSTOR models. From Fleisher et al. 2000.

II.2.3 Dynamic mass balanced models

The dynamic mass balance models for the microbial compartment of MELiSSA were obtained coupling a stoichiometric mass balance equation with a kinetic (growth rate, production or consumption rate) and hydrodynamic equation describing the process (TN 39.1). The HPC dynamic mass balance model is quite different.

First the dynamic is a gas flow dynamic, depending of fan and design of the HPC chamber. It does not directly influence the growth if these environmental conditions (humidity, temperature, composition) are well controlled.

Secondly, as previously remarked, the plant growth is a cycle with in fact various metabolic states and probably various growth yields. The mass balance equation previously established are an average for the whole life cycle. We aren't certain that a coupling of the average mass balance equation for edible and non edible plant with a kinetic rate (the best being the net photosynthetic rate in CO_2 consumed/time and the respiratory rate) can be representative of the different life cycles of the plant.

One simple representation of the dynamic mass balance model of plant can then be written :

$$\frac{dC}{dt} = \frac{1}{Y_{g/C}} Pg + \frac{1}{Y_{R/C}} R \text{ for each compound C}$$

Pg being the photosynthetic growth rate and R the respiratory rate (in CO_2/time) as detailled in section II.2.2, and $Y_{g/C}$ and $Y_{R/C}$ being respectively the yield reported to CO_2 for compound C in the growth mass balance equation (including edible and non edible) and in the respiration equation.

This approach is exactly which was used by Wignarajah et al. (2000) for the estimation of the nutrient uptake rate by plants.

II.3 Conclusion : Higher Plant modelling strategy

The higher plant are introduced in ALSS for their food production capabilities. Even if they are able to care of other life support function (water purification, O_2/CO_2 exchanger…) there are other biological and physico-chemical processes which are more manageable and simple. These which can be used for these functions (algae, micro-organisms). Then the definition of a HPC is linked to the diet strategy and its design is based on the diet, nutritional and menu constraints. That the reason why HPC is always described and defined from the crew diet and menu requirement.

It is preferable to optimise a HPC using menu based constraints, nutritional constraints being not sufficient to obtain a large panel of menu for a crew. Most of the parameters for crop cultivation and food processing can be found, but it is required to organise and to sort this knowledge. We believe that the building of a kind of a database for plants, food processing and food would be a usefully tool for the MELiSSA teams. We propose a first template in appendix D.

Since the 70's, higher plant were extensively studied as core element for BLSS. Nevertheless at our knowledge there is no full dynamic mass balance model for plants (as those developed for micro-organisms). The complexity and the variability of the growth with environmental conditions being probably one of the reasons. For developing models for the plants in MELiSSA, a choice must be made within the models used and/or developed for controlled crop growth: "top level models", "modified agricultural and ecological model" (such as CERES, SUBSTOR…), these two kinds being parametric models , and non-parametric models (Cloutier et al., 2000).

The strategy chosen for the control of the HPC must be taken into account in the choice of the kind of the model. It can be noticed that for a control of the dry weight of a plant by integrated photosynthetic photon flux (PPF), a "top level model" was used by Fleicher et al. (2000).
Considering that the goal of HPC compartment is to produce food, we believe that, the main control must be the weight of the plant (which must be estimated by modelling approaches only, knowing that this variable cannot be measured during the growth). Consequently, this entails that the other plant-growth associated activities (i.e. O_2/CO_2 exchange rates) will not be controlled.

III Equivalent System Mass methodology

III.1 Equivalent System Mass (ESM) : Definitions

Equivalent System Mass

Equivalent System Mass was selected in 1999 as the basis of the NASA Advanced Life Support Program Research and Technology Development Metric. It was the answer to the Government (US Government) Performance and Results Act (GPRA) enacted in 1993 which requires that federal agencies (namely NASA for space), develop annual performance plans that include quantitative measures of their progress (Levri et al, 2000).
ESM evaluates the mass of a system or subsystem and associated infrastructure costs, given a specific mission location, duration and crew size. ESM translate in a single variable, equivalent to a mass unit which should be noted kg-ESM, five components characterising an ALS system or subsystem, namely : (1) the system mass, (2) the system occupied volume , (3) the system power requirements, (4) the system cooling requirement and (5) the crew time requirements (i.e. maintenance and labour time).

ESM Metric

NASA has defined an ESM metric, or “ALS metric”, as :

$$\text{ESM Metric} = \frac{\text{ESM of the LSS using the current ECLSS technology of ISS}}{\text{ESM of the (same) LSS using an ALSS technology}}$$

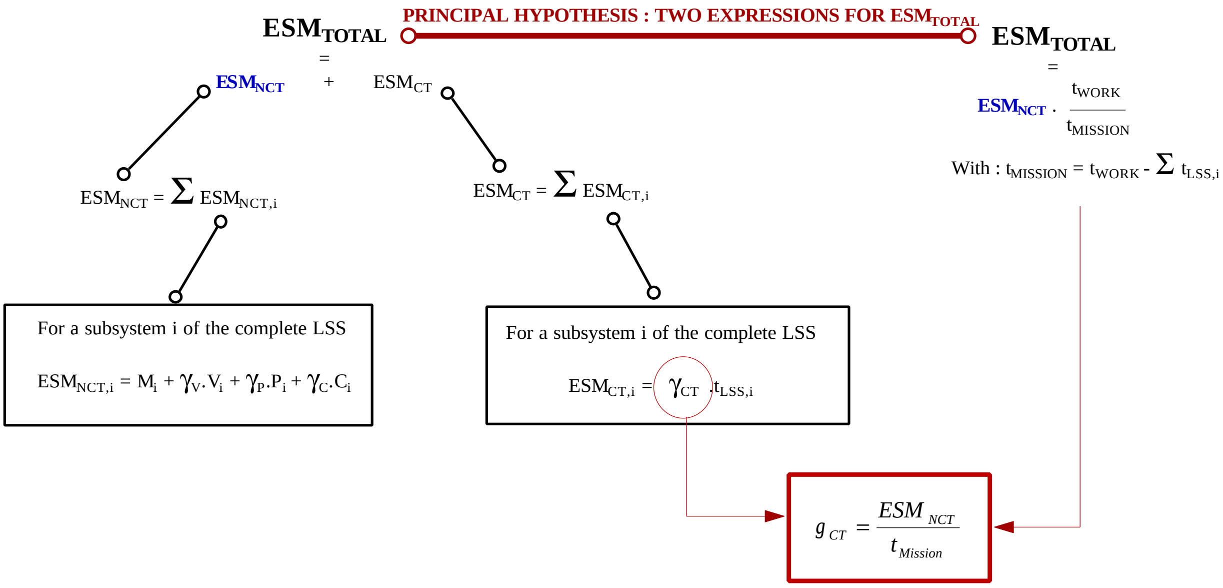
If the ESM-metric is less than 1, this means that current ISS-ECLSS technology is more interesting tan any other advanced Life support system (at the current knowledge of ALSS). If ESM-metric is greater than 1, it is interesting to study and develop advanced technology for improving the mass requirements associated to life support.

However, it must be emphasised that it may be important to develop systems that are not currently optimised (ESM <1) in order to minimise the embarked mass in subsequent studies and ESM-metric can also be used to “measure” the advance in the improvement of technology. This is particularly true for biological systems which are not presently advantageous in terms of mass, mainly because the studies are currently at their first steps.

III.2 Equivalent System Mass (ESM) : Theory

III.2.1 ESM calculation principles

The first step in the calculation of the ESM is to determine all the components without consideration of crew time. The ESM portion attributed to crew time is further calculated from the non crew time ESM portion (Levri et al, 2000).



ESM_{TOTAL} : ESM of the entire LSS (kg-ESM)

ESM_{NCT} : non crew time ESM portion of the entire LSS (kg-ESM) - include mass, volume, cooling and power requirement of all subsystems.

ESM_{CT} : crew time ESM portion of the entire LSS (kg-ESM) – account for maintenance, repair and operating the life support system.

t_{WORK}: crew time available for working during the mission (h.person^{-1}. week^{-1})

$t_{LSS,i}$: crew time required to support subsystem i (h.person^{-1}. week^{-1})

$t_{MISSION}$: crew time available for the mission operations and experiments (h.person^{-1}. week^{-1})

Subsystems :

$ESM_{NCT,i}$: non crew time ESM portion of the subsystem i (kg-ESM).

$ESM_{CT,i}$: crew time ESM portion of the subsystem i (kg-ESM)

Mi : mass of subsystem i (kg-ESM = kg)

Mi can be time dependant, for non closed systems which involved re-supply

Vi :volume of subsystem i (m^3)

Pi : power requirement of subsystem i (kW)

Ci :cooling requirement of subsystem i (kW)

g_V :volume infrastructure cost factor (kg-ESM.m^{-3})

g_P : power infrastructure cost factor (kg-ESM.kW^{-1})

g_C : cooling infrastructure cost factor (kg-ESM.kW^{-1})

g_{CT} : crew time cost factor (kg-ESM.person.week.h^{-1})

at the contrary of other costs factor g_{CT} **is not constant:** $g_{CT} = \dfrac{ESM_{NCT}}{t_{Mission}}$

Figure 7-1 : Principles and theory of ESM calculation

The hypothesis for the ESM calculation is that the total ESM of the system can be written with two different expressions :

$$ESM_{TOTAL} = ESM_{NCT} + ESM_{CT}$$

$$ESM_{TOTAL} = ESM_{NCT}.(1+\frac{t_{LSS}}{t_{Mission}}) = ESM_{NCT}.\frac{t_{Work}}{t_{Work}-t_{LSS}}$$

then ,

$$ESM_{CT} = ESM_{NCT}.\frac{t_{LSS}}{t_{Mission}} \text{ and } g_{CT} = \frac{ESM_{NCT}}{t_{Mission}}$$

ISS ECLSS Infrastructure Costs				
	Factor	Value	Units	Comments
	Mass Delivery Factor	2	kg packaged /kg unpackaged	For components requiring packaging (food and clothing)
	Pressurized Volume	0.015	m³/kg-ESM	ISS common module; No shielding or secondary structures
	Power	11.4	W/kg-ESM	Nuclear power; Based on SP100 Program
	Heat Rejection	25.4	W/kg-ESM	
	Crew Time	2	Person•hr/kg-ESM	A rough estimate
Derived Costs for Mission				
	Energy	492.48	kWh/kg-ESM	
	Heat Rejection	3,950.2	kWh/kg-ESM	

Table 4 : Example for infrastructure cost factors for the International Space Station. (Drysdale and Hanford, 2000)

Factor	Value	Comment
Volume	66.7 kg-ESM.m^{-3} 2.08 kg-ESM.m^{-3} 16.1 kg-ESM.m^{-3}	ISS aluminium module Inflatable TransHab-type structure Inflatable structure with radiation shielding
Power	476.2 kg-ESM.kW^{-1} 76.9 kg-ESM.kW^{-1} 83.3 kg-ESM.kW^{-1} 86.9 kg-ESM.kW^{-1}	LEO for continuous power generation LEO for power generation during sunlight only solar activated photovoltaic cells nuclear reactor SP100 class
Cooling	163.9 kg-ESM.kW^{-1} 21.1 kg-ESM.kW^{-1} 66.7 kg-ESM.kW^{-1}	body-mounted radiator for LEO body-mounted radiator for transit missions body-mounted radiator or deployed systems for Mars base

Table 5 : Cost factors cited by Levri et al. (2000).

III.2.2 The five components

Mass

The mass component of ESM accounts for:

- the fixed mass. This is the initial mass of the system (at least equipment mass), excluding mass accounted for such as pressurised volume and infra-structure.
- the time dependent mass and even dependent mass, i.e. the re-supply for completing habitability requirement and sink (EVA)

It must be outlined that the fixed mass can be dependent on the performance level (quality, quantity, safety) of the system, or subsystem. The mass must account the time dependent processes to avoid breaks in the LSS functions, and then it is the "working mass" of the system or the subsystem that must be considered (Levri et al., 2000). For MELiSSA, this means that the bioreactors must be sized to have optimal degradation/production efficiencies (Poughon, 2000) and to take into account the "buffer" effect of some part of the loop. Another example given by Levri et al. (2000) concerns the working mass of the laundry subsystem which must account for the mass of the equipment and for the mass of clothing use to replace the clothing that is unavailable to the crew during the laundry processing.

Volume

As for mass, a fixed and a time dependent volume must be considered. Fixed volume accounts for the volume required by the unit itself and by all contingency, consumable and maintenance materials. The volume allotted for the crew access to the subsystem must be added to the volume of the subsystem.

It is important to notice that volume can be share or common between several subsystems. Therefore the volume estimated is not necessarily the sum of the volumes of all subsystems. This supposes to have an integrated view of the subsystems, of their interfaces and their interrelations, i.e. to have designed the LSS.

The volume infrastructure cost factor accounts for the pressurised space depends on the design of the module and the material used (Drysdale et al., 2000). The cost factor values given in Table 4 are estimated for a common module without secondary structure or meteorite shielding. For baseline missions, a habitable volume of 50 m^3 per person is assumed (Levri et al, 2000), giving volume cost factors of :

66.7 kg-ESM.m^{-3} for an ISS aluminium module
2.08 kg-ESM.m^{-3} for an inflatable TransHab-type structure for a mars surface mission module
16.1 kg-ESM.m^{-3} for an inflatable structure with radiation shielding

Power requirement

The power requirements can be considered by two different approaches.
The first one is the average approach, which is traditionally used. For cyclic processes (as light /dark period for plants) this means to calculate the average power requirement along one complete cycle.
The second one is the dynamic approach. This approach takes into account power requirements peaks.

The average approach is more appropriate for steady-state subsystems or systems. The dynamic approach require to investigate power management techniques and strategies with may be used for smoothing power profiles, allowing available power to be scheduled and

distributed in accordance with the demand. As for volumes, this supposes to have a deeply integrated view of all the subsystems of the LSS.
Several power cost factors have been proposed, depending on the missions scenarios and on the power supply source (Levri et al. ,2000):

476.2 kg-ESM.kW^{-1} in LEO for continuous power generation
76.9 kg-ESM.kW^{-1} in LEO for power generation during sunlight only
83.3 kg-ESM.kW^{-1} in Mars mission transit, using solar activated photovoltaic cells
86.9 kg-ESM.kW^{-1} in Mars base mission, using a nuclear reactor SP100 class (separate building)

Cooling requirements

Most of power consumption that is consumed is rejected as heat (**i.e in Tables 6-4 and 7-3 power = cooling**). Human activity itself produces heat, but we do not know if it is taken into account. The total cooling requirement is traditionally considered equal to the power load (Levri et al, 2000).

Nevertheless some differences between power supply and cooling requirement exist as :

- biological or chemical reactions can be endothermic or exothermic, but the effect is in principle negligible compared to power involved in processes.
- for plant, the choice of the light source (type of lamps, direct sunlight), doesn't require the same cooling
- thermal regulation can exist within the subsystem (condenser, controlled temperature of reactors,…)
- coupling between subsystems can be made (heat-exchanger)

Whatever the heat load, the type of heat rejection system which is selected determines the cooling infrastructure cost factor. The sink temperature used for the heat rejection system (space, Mars surface,…) is also important. For baseline missions, it is assumed that heat rejection is performed with lightweight, inflatable radiator with equipment that is cold plated where possible. This results in cooling cost factor of (Levri et al, 2000) :

163.9 kg-ESM.kW^{-1} for body-mounted radiator for LEO
21.1 kg-ESM.kW^{-1} for body-mounted radiator for transit missions
66.7 kg-ESM.kW^{-1} for body-mounted radiator or deployed systems for Mars base

Crew time

The crew time is divided into :

- the mission time, including EVA, IVA.
- the LSS time, used to maintain LSS system and subsystems.
- the other time, including personal time, sleeping, eating exercising

Mission time and LSS time are the effective Work time for the crew. It is assumed to be about t_{Work} = 66 h.person^{-1}.week^{-1} in LEO (Levri et al., 2000).

In BIOS-3 experiments (Gitelson, 1999), the following average crew work time calculated was 94.5 hours (note that exercises are not included in the 73.5 5 $h.person^{-1}.week^{-1}$) and distribution of the crew time was:

> 15. $h.person^{-1}.week^{-1}$ for maintaining and operating the higher plant link *(t_{LSS})*
> 20.5 $h.person^{-1}.week^{-1}$ for maintaining and operating the algae cultivators *(t_{LSS})*
> 73.5 $h.person^{-1}.week^{-1}$ for sleeping, eating, cooking, hygiene
> 59 $h.person^{-1}.week^{-1}$ other activities *($t_{MISSION}$)*

For the above data, we can calculate :

$t_{LSS} = 15 + 20.5 = 35.5\ h.person^{-1}.week^{-1}$

$t_{Mission} = 59\ h.person^{-1}.week^{-1}$

$t_{Work} = t_{LSS} + t_{Mission} = 35.5 + 59 = 94.5\ h.person^{-1}.week^{-1}$

$t_{Total} = t_{Work} + t_{Rest} = 168\ h.person^{-1}.week^{-1}$ (i.e. 24 $h.person^{-1}.day^{-1}$)

III.2.3 ESM application : procedure (Levri et al., 2000)

This section describes the procedure suggested by Levri et al. (2000) for using the ESM approach as previously presented, for the analysis of a new subsystem in a defined baseline mission scenario and LSS.

This procedure implicitly supposes to know the baseline mission scenario and the LSS (system and subsystems) associated. This procedure presents the calculation of the Crew Time ESM for the mission scenario with a knew subsystem 'X', but is also available for the calculation of the ESM of a completely new mission scenario and LSS.
NASA considers 4 kinds of missions : LEO laboratory (the ISS baseline) ; Mars surface missions (independent or concentrated missions) ; extended presence missions (permanent bases) and transit missions. Drysdale and Hanford (2000) group 3 missions baseline by the LSS technology: ISS technology ; Physico-Chemical-ALSS technology and Biological-ALSS technology (report toIII.3).

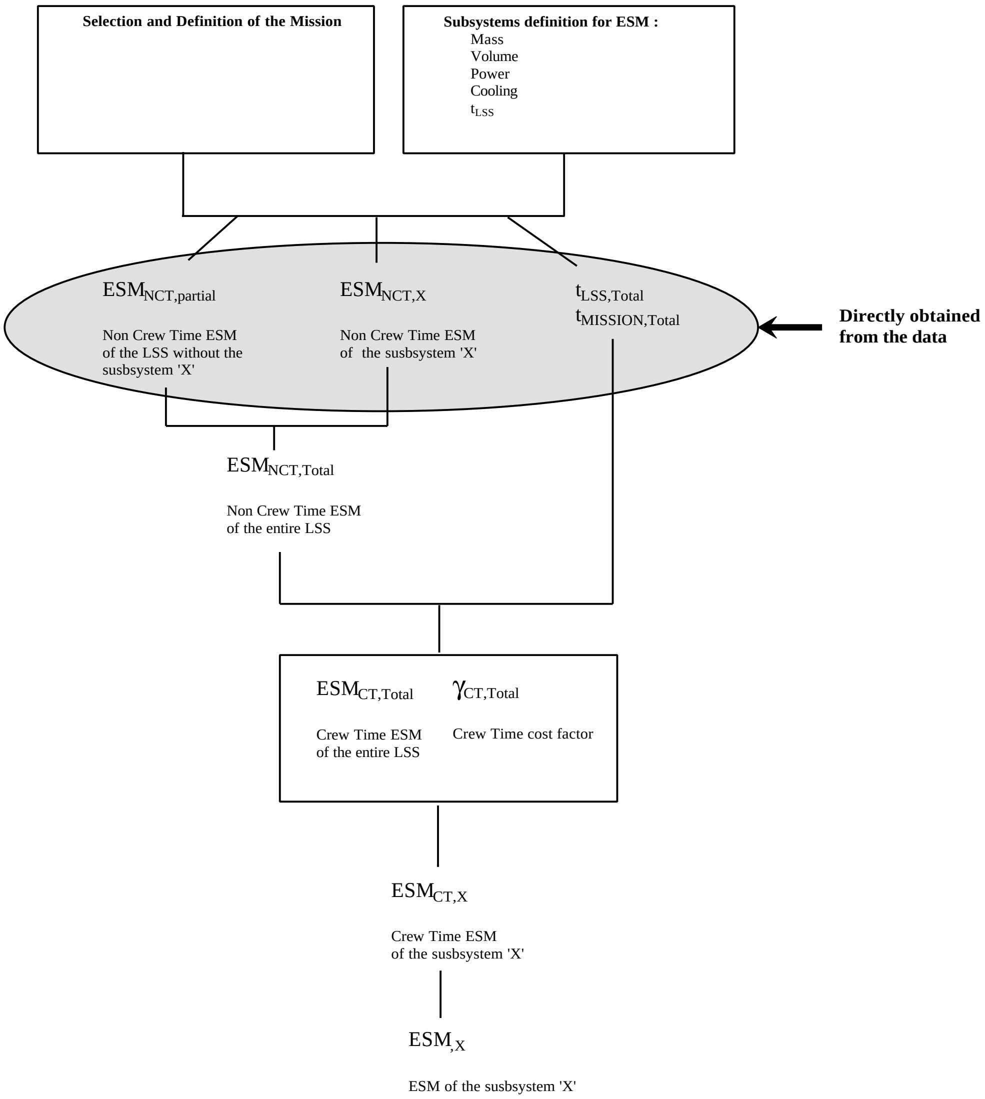


Figure 7-2 : Procedure for the calculation of the ESM of a subsystem 'X' and of its impact on a mission scenario (Levri et al., 2000)

III.2.4 Remarks and critical points of ESM calculation

(1) ESM and LSS characteristics and constraints

As can be remarked in the previous description of the ESM calculations, the system for the ESM is never detailed in term of closure (or self sufficiency) or in terms of stability and reliability. In fact, whatever the system is (and whatever is the mission and its duration), it is implicitly assumed that the system is able to support all the functions of a LSS and to satisfy the same life support quantity, product, quality, reliability and safety requirements.

But in the literature used (Levri et al, 2000; Drysdale and Hanford, 2000 ;Drysdale et al., 2000) it is difficult to know exactly what are the constraints and the design of the LSS, and how they are used. Even if Levri et al. (2000) have noticed that better calculation of the ESM would be obtained using a dynamic approach, rather than a static approach (steady-state and average approach), all results that we have found only concern calculation for steady-state.

(2) LSS and subsystems interrelations
As outlined by Levri et al (2000), the interactions between subsystems of an LSS can have an important influence on the ESM calculation, but it can be noticed that the procedure proposed in Figure 7-2 does not seems to take into account new interactions introduced by changing a subsystem. We estimate that if a subsystem introduces new interrelations, the design of the LSS must be re-evaluated and ESM calculations must be completely recalculated as characteristics of the subsystems (mass, volumes, power, cooling) can change.

(3) ESM and closure
Drysdale (2000) considers that it is better to consider self sufficiency of the system than closure of the system. Self sufficiency means that requirements (for crew) are met, what is the basic constraint for the definition of a LSS. Closure analysis (close or partially closed system) suppose that mass balance analysis of the system is performed. We believe that we can interpret closure as a higher degree of analysis of a system, considering that self sufficiency notion can finally result from the fact that the interrelations between subsystems were only partially investigated.

(4) ESM and crew time cost factor
The crew time cost factor of the LSS is calculated assuming that this cost factor is proportional to the ESM_{NCT} of the LSS and to t_{LSS}. It is an important assumption which increases the ESM penalty of systems with high ESM_{NCT} as illustrated in the following Figure 8 (hyperbolic shape).

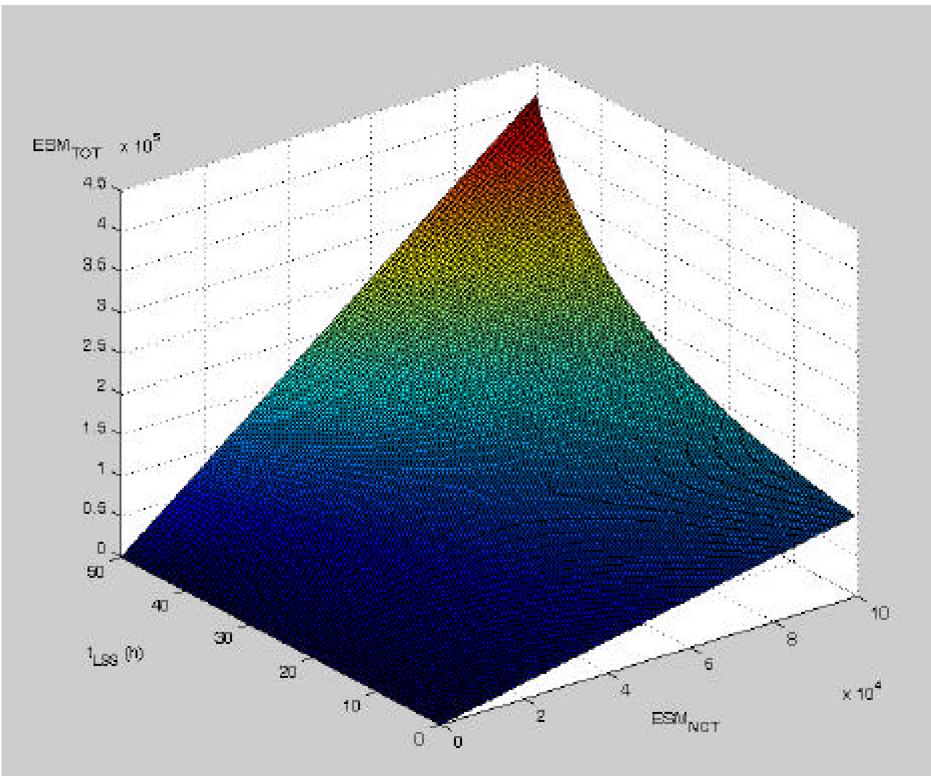


Figure 8 : ESM as function of ESM_{NCT} and t_{LSS} (assuming t_{WORK} = 66 h.person^{-1}.week^{-1})
(t_{LSS} : 0-50h.person^{-1}.week^{-1} ; ESMNCT : 0 – 100000 kg-ESM)

We have outlined these 4 points, as they can be compared with the strategy chosen for the numerical analysis of the MELiSSA loop.
MELiSSA loop modelling is based on mass and elements balances and then system performance have been so far studied considering the closure of the loop as prime variable.
We believe that closure is an important element to associate to ESM analysis. The closure analysis entails having a view of the interrelations between subsystems and to define constraints and variables used for the LSS and its subsystems, which are not often always clearly detailed in ESM analyses.

III.3 Comparison of ESM value of different systems

Comparison of LSS options is the main objective of ESM (ESM-metric). This method is used by NASA for the analysis of baseline missions scenario with various LSS technology. Here some examples are presented.

The baselines missions defined by NASA are LEO station (ISS), Mars mission (independent and concentrated missions) and extended presence on Mars (permanent base). It can be noticed that the missions scenario defined by HUMEX (HUMEX TN1 , 2001) are of the same kind (500 days Mars mission ; 1000 days Mars missions and Moon permanent base).
The technologies evaluated with ESM-metric are of 3 kinds : ISS technology (systems operating in the ISS), ALS Physico-chemical technology and ALS bioregenerative technology.

The ESM calculations presented by Drysdale and Hanford for the ISS with the baseline ECLSS and a PC-ALSS. are reported here.
It must be kept in mind that the values are rough estimates, especially for ALSS technologies which lack of maturity, and would probably change. Nevertheless, these results are interesting because they well illustrate the principles of ESM and ESM-metric, as used for evaluation of LSS option and scenario.

(1) ISS ECLSS baseline
Tables 6 and Figures 9 are for ISS ECLSS baseline analysis. Tables 6-1 and 6-2 are important because they contains the informations used for the description of the LSS constraints. Table 6-3 summarise the key values for ESM calculations. Table 6-4 present the technologies used and give their corresponding ESM equivalencies. The authors did not detailed the values presented in Table 6-4. The design of the LSS itself, of its performances and of the interrelations between subsystems are not described. These data are important as ISS technology is used as the basis in ESM-metric calculations.

For 10 years the ESM calculated by Drysdale and Hanford (2000) is 147 886 kg-ESM. The ESM time dependant formula given by Drysdale (2000) is [5400 + 16600 * years], i.e. 171 400 kg-ESM for 10 years. The two values are in the same order, which illustrates the variability of the ESM values.

(2) ALSS technology baseline example

The example reported here was calculated by Drysdale and Hanford (2000) for a reference Mars mission :

Using a TransHab-style inflatable structure for the crew module;
Assuming a single vehicle for transit mission between Earth and Mars;
Assuming a separate vehicle for transfer to Mars surface;
Technology selection (Table 7-3) process did not consider surface operation.

The system requirements are given in Table 7.1 and the cost factor are reported in Table 7.2. The ESM calculation presented are only indicative because ALSS technology maturity is lower than the ISS technology. The time dependant ESM is :

Technology detailed in Table 7-3 : kg-ESM = [9057 + 9234.5 * years]

Other ESM calculation are proposed by Drysdale et al. (2000), using various options for lighting the plants compartments :

BIOPLEX technology :	ESM (kg/m^2) = 467 + 53.7 * years
Advanced electrical lighting	ESM (kg/m^2) = 367 + 27 * years
Natural sunlight	ESM (kg/m^2) = 73 + 9.8 * years
Natural sunlight x4	ESM (kg/m^2) = 292 + 39.2 * years

The results are summarised in Figure 10.

ISS ECLSS BASELINE
(from Drysdale and Hanford, 2000)

ISS ECLSS Mission Definition Data		
Number of Crew	4	USOS only
Nominal Duration	3,650	days at the same site, or 10 Earth years.
Location	LEO	

Table 6-1: Mission definition
(USOS=US on Orbit Segment, of the ISS)

ISS Food and Clothing Components (kg/(personn.day)	
Required Food (hydrated)	1.955
Total Food Mass	3.910
Clothing	1.4
Packaged Clothing	2.8

Table 6-2: Requirements/constraints definition

ISS ECLSS Infrastructure Costs		
Mass Delivery Factor	2	kg packaged /kg unpackaged
Pressurized Volume	0.015	m³/kg-ESM
Power	11.4	W/kg-ESM
Heat Rejection	25.4	W/kg-ESM
Crew Time	2	person•hr/kg-ESM

Table 6-3 : Cost factors for ESM calculations (report also to table 4)

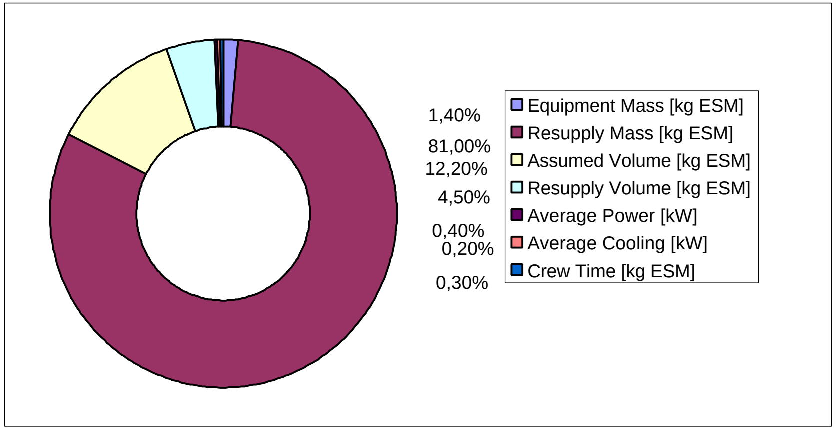


Figure 9-1 : ESM distribution by ESM components

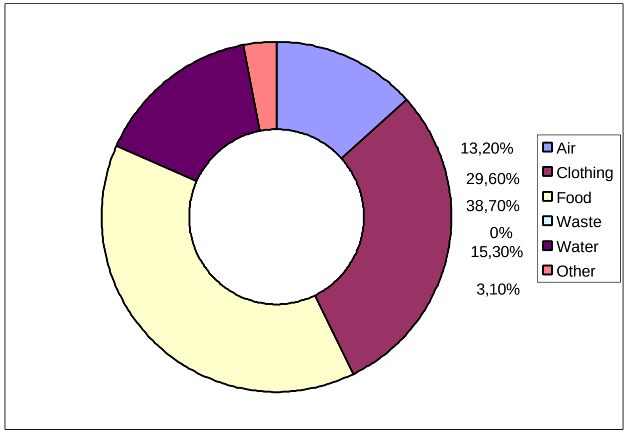


Figure 9-2 : ESM distribution by functions

International Space Station Environmental Control and Life Support System (excluding equipment for Extravehicular Activities and Airlock operations)

			Average		Assumed		Resupply		Average	Average			System	Percentage
System / Item	Mass [kg]	Volume [m³]	Power [kW]	USOS Num	Mass [kg]	Volume [m³]	Mass [kg]	Volume [m³]	Power [kW]	Cooling [kW]	Crew Time [per•hr/yr]	ESM [kg ESM]	ESM [kg ESM]	of Total ECLSS
Air Revitalization System (ARS)													2,901.3	2.0%
Carbon Dioxide Removal Assembly (CDRA)	201.0	0.39	0.860	1	201.0				0.86	0.86	2.7	323.8		
Trace Contaminant Control Subsystem (TCCS)	78.2		0.175	1	78.2		163.0	0.340	0.18	0.18	4.4	1979.0		
Major Constituent Analyzer (MCA)	54.7	0.44	0.088	1	54.7		12.0	0.023	0.09	0.09	0.4	203.5		
Oxygen Generation Assembly (OGA)	113.0	0.14	1.470	0.57	64.6		12.7	0.010	1.47	1.47	2.0	395.1		
Temperature and Humidity Control System (THCS)													1488.9	1.0%
Common Cabin Air Assembly (CCAA)	112.0	0.40	0.468	3	336.0	1.200			1.66	1.66		627.0		
Avionics Air Assembly (AAA)	12.4	0.03	0.083	3	37.2	0.102			0.25	0.25		75.8		
Intermodule Ventilation (IMV) Fan	4.8	0.01	0.055	5	24.0	0.045			0.22	0.22		55.0		
Intermodule Ventilation (IMV) Valve	5.1	0.01	0.006	15	76.5	0.149			0.01	0.01		87.2		
High Efficiency Particle Atmosphere (HEPA) Filter	2.0	0.01		15	30.0	0.120	47.0	0.189			2.0	644.0		
Fire Detection and Suppression													75.1	0.1%
Smoke Detector	1.5		0.002	8	12.0							12.0		
Portable Fire Extinguisher (PFE)	15.1	0.04		4	60.4	0.041						63.1		
Crew Cabin													15101.4	10.2%
Volume: 50 m³/person		200.00				200.000						13333.3		
Air: 1 volume of gas	258.9				258.9							258.9		
Leakage Rate: 83 kg/(module•yr)							150.9					1509.1		
Vacuum System	*The largest item is 10 kg - negligible*												0.0	
Water Recovery and Management (WRM) and Waste Management (WM)													22674.3	15.3%
Water Processor (WP)	476.0	10.39	0.300	1	476.0		478.0		0.30	0.30	6.0	5324.1		
Process Control Water Quality Monitor (PCWQM)	38.0	0.51	0.030	1	38.0				0.03	0.03	1.0	46.8		
Urine Processor (UP)	128.0	0.37	0.091	1	128.0		175.0	2.178	0.09	0.09	13.0	3406.6		
Fuel Cell Water Storage	21.0	0.10		4	84.0		684.0					6924.0		
Condensate Storage	21.0	0.10		1	21.0							21.0		
Commode / Urinal	50.0		0.072	1	50.0		435.0	3.364	0.07	0.07	60.0	6951.8		
Other Miscellaneous													105645.1	71.4%
Food							5708.6		1.61	1.61		57290.7		
Clothing							4114.5	3.857				43717.0		
Miscellaneous Power									0.25			22.0		
ECLSS Racks (10)						69.230						4615.3		
Total ISS ECLSS	**1593**	**212.9**			**2031**	**270.89**	**11981**	**9.96**	**7.1**	**6.8**	**91**	**147886**		

Table 6-4 : ECLSS equipment for the ISS

ALSS TECHNOLOGY BASELINE
Example for a 400 Days Mars Mission
(from Drysdale and Hanford, 2000)

Physical Quantity	Value	Units
Crew Size	6	people
Mission Duration	400	days
Cabin Atmosphere		
Total Cabin Pressure	59.2	kPa
Partial Pressure – Oxygen	17.8	kPa
Partial Pressure – Carbon Dioxide	0.4	kPa
Leakage Rate	0.76	kPa
Human Consumption		
Food	11.8	MJ/(person•day)
Oxygen Consumption	0.835	kg/(person•day)
Carbon Dioxide Production	0.998	kg/(person•day)
Water Usage		
Water Consumption (Food & Drink)	3.52	kg/(person•day)
Hygiene Water Usage	4.44	kg/(person•day)
Shower Water Usage	2.72	kg/(person•day)
Urinal Flush Usage	0.49	kg/(person•day)
Dish Wash Usage	5.44	kg/(person•day)
Clothing Wash Usage	12.47	kg/(person•day)
Total Water Consumption / Usage	29.08	kg/(person•day)

Table 7-1 : System requirements and constrains

ALSS Infrastructure Costs		
Mass Delivery Factor	2	kg packaged /kg unpackaged
Pressurized Volume	0.015	m³/kg-ESM
Power	12.0	W/kg-ESM
Heat Rejection	25.4	W/kg-ESM
Food	1.725	kg/(per•day)
Clothes	0.267	kg/(per•day)
Spares & Expendables	15%	

Table 7-2 : Cost factors for ESM calculations

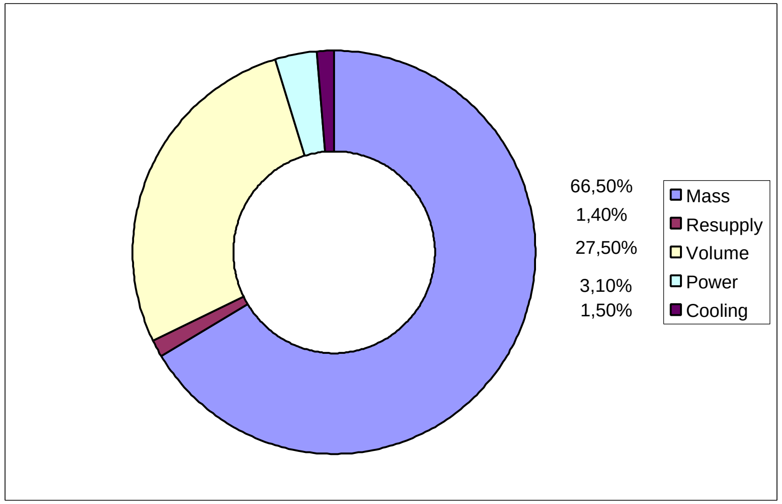


Figure 10 : ESM distribution by ESM components (for the entire mission duration)

The ESM is time dependant :

ESM = 9057.9 + 25.3 t

(t in day ; ESM in kg-ESM)

An Advanced Life Support System (based on physicochemical technologies and estimates for TransHab)						
Air Revitalization System	Technology Assumed [Program] / Notes	Mass [kg]	Resupply [kg]	Volume [m³]	Power [kW]	Cooling [kW]
Air Pressure	ARPCS [X-38]	74.0	11.1	0.41	0.100	0.100
Oxygen/Nitrogen Storage	high pressure [Space Transportation System (STS)]	284.0	0	1.21	0.008	0.008
Humidity Control	anti-microbial condensing heat exchanger [LMLSTP Ph IIA]	46.0	6.9	0.26	0.400	0.400
Air Temperature Control	anti-microbial condensing heat exchanger [LMLSTP Ph IIA]	99.0	14.9	0.74	0.370	0.370
Carbon Dioxide Removal	[Node 3]	176.0	13.8	0.45	0.365	0.365
Carbon Dioxide Reduction (a)	Sabatier	31.0	4.2	0.44	0.130	0.130
Oxygen Production (a)	Solid Polymer Water Electrolysis (SPWE)	120.9	18.0	1.12	1.840	1.840
CO_2 Reduction/O_2 Production (b)	Salad Machine / This item is carried in food production.					
Trace Contaminant Control	[Node 3]	77.0	5.6	0.14	0.128	0.128
Particulate and Microbe Control	reusable filters	7.0	1.1	0.08	0	0
Air Pressure Monitoring	sensors [International Space Station (ISS)]	2.0	0.3	0	0.005	0.005
Air Composition Monitoring	[Space Transportation System (STS)]	6.0	0.9	0	0.015	0.015
Fire Detection and Suppression	smoke detector and halon	19.0	2.9	0.05	0.050	0.050
Crew Cabin Volume	[TransHab] / The mass of gas is assumed to be elsewhere.			300.00		
Water Recovery System	Technology Assumed [Program] / Notes	Mass [kg]	Resupply [kg]	Volume [m³]	Power [kW]	Cooling [kW]
Urine Pretreatment	flush + solid agent / This item is included in water storage.					
Urine Processing	Bioreactor + Reverse Osmosis + Air Evaporative Subsystem	175.0	87.0	0.60	1.450	1.450
Hygiene Waste Storage	Bladder-less tanks	203.0		0.64		
Hygiene Waste Processing	Bioreactor + Reverse Osmosis + Air Evaporative Subsystem	76.0	6.9	0.99	0.200	0.200
Hygiene Waste Post Processing	Milli-Q + ammonia removal	56.0	8.0	0.55	0.540	0.540
Microbial Control	iodine microbial check valve	10.0	1.5		0.012	0.012
Water Quality Monitoring	Water Quality Monitoring (WQM) [ISS]	39.0	5.9	0.08	0.100	0.100
Potable Water Storage	bladder-less tanks	950.0		1.61	0.020	0.020
Waste Handling & Processing	Technology Assumed [Program] / Notes	Mass [kg]	Resupply [kg]	Volume [m³]	Power [kW]	Cooling [kW]
Urine Collection	Waste Management Subsystem [ISS] / This item is included with feces collection.					
Urine Storage	bladder-less tanks	49.0		0.32		
Feces Collection and Storage	Waste Management Subsystem [ISS]	103.0	15.5	1.28	0.340	0.340
Other Solid Wastes	trash compactor [International Space Station (ISS)]	27.0	4.1	0.09	0.060	0.060
Solid Waste Processing	stabilization + disposal and incineration	225.0	33.8	2.38	0.265	0.265
Solid Waste Disposal	overboard jettison [International Space Station (ISS)]	59.0	8.9	1.77	0.130	0.130
Miscellaneous	Technology Assumed [Program] / Notes	Mass [kg]	Resupply [kg]	Volume [m³]	Power [kW]	Cooling [kW]
Food Supply	storage [ISS] and on-board production / This item is included in Crew Accommodations; 100% food provided.					
Regenerative Food Production	Salad Machine / Less than 10% production.	120.0	18.0	1.94	0.650	0.650
System Monitoring and Control	intelligent monitoring and control (M&C)	20.0	3.0			
System Operations Planning	artificial intelligence (AI) expert system / Included in M&C					

Crew Accommodation System	Technology Assumed [Program] / Notes	Mass [kg]	Resupply [kg]	Volume [m³]	Power [kW]	Cooling [kW]
Food	1.725 kg/(person•day)	8,280.0		8.28		
Clothes	0.267 kg/(person•day)	1,279.2		1.28		
Laundry		118.2				
Totals		**12,739.4**	**271.8**	**326.70**	**7.178**	**7.178**

Table 7-3 : ALSS equipment for the defined mission

III.4 Application of the ESM approach for the MELiSSA loop analysis

In section III.2.4 our mains remarks concerning the ESM methodology have been presented. It can be noticed that these remarks are based on the observation that the views of the LSS are not detailed and then that the performances and the interrelations between subsystem are not clearly presented, even if some seems to be taken into account as can be seen in the details of Table 7-3 (for the urine treatment).

It is important to notice that the current MELiSSA loop approach is different of the ESM approach. Models and simulations of the loop were performed in order to calculate the overall performances of the loop in term of recycling efficiencies or in terms of closure, the system itself (including re-supplies) being self sufficient, by using the mass balance associated to the integrated view of the system (interrelation between biological subsystems).

The examples presented in section III.3 (Figures 9-1 and 10) show that mass and volume are the main part of the ESM calculation. Consequently the calculation of the MELiSSA loop performances to estimate the size of the loop (in term of liquid volume) (Poughon , 2000) are also a good indicative values for starting comparisons between LSS with various options.

Nevertheless this must be completed by calculating not only the liquid volume but also the equipment volume/mass/power requirement/cooling of the compartments, leading to evaluate the loop itself. By this way we will tend to an approach comparable to the ESM calculation.

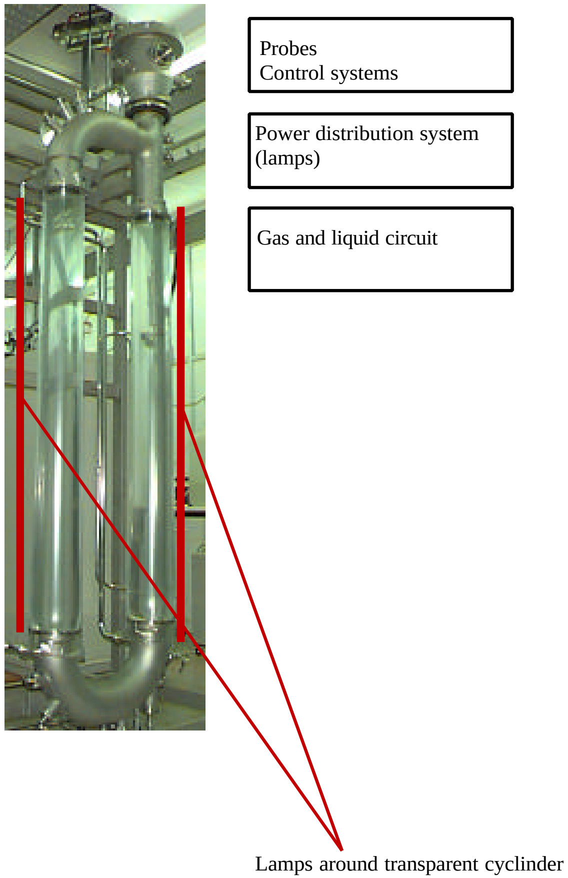
As noticed in section III.2.4, the calculation of the crew time requirement is more complicated. There is probably a part of the crew time which is proportional to the size of the system, but there is probably also a crew time which is not dependant of the size. The method used in ESM is very sensitive, and then must be carefully used as it can mask some aspects of the system.

In the objective of a better analysis of the MELiSSA loop and of its compartments, a technical data base must be developed, which will enable to calculate requirement and performances of each compartment (or subsystem).

A first step is made by proposing here a template, illustrating a “Spirulina photobioreactor”. The fourth compartment of MELiSSA is presented as a subsystem, detailing:

- its functions
- its operating constraints
- its performances
- its interrelations with other subsystems (but the quantity of matter exchanged can only be evaluated with modelling and simulation of the entire LSS)
- its operating characteristic value which can be used in an ESM approach

Spirulina Photobioreactor	UAB Spirulina PBR [References : TN25.1 ; TN 37.2 ; TN 43.110]



Reactor type :
Airlift

Reactor dimensions :
Connecting tubes (transparent) : 0.12 m x 1.5 m
Working volume : 77 liter
Illuminated volume : 53 liter
Illuminated area : 1.41 m^2

Material :
Up/down tubes : polyamide foil
Connecting pipes : stainless steel

Lamps :
Number : 350
Type : sylvania 12V 20 W
Characteristics : maximum power – 7000 W

Operating conditions :

Temperature : 36°C
PH : 8 –10
Liquid flow rate : 0 – 4 10^{-2} h^{-1} (0 – 3.1 l/h)
Gas flow rate : 2 VVM (looped gas circuit)

Performances :
20 W/m^2 → 21 g O_2/day
250 W/m^2 → 94 g O_2/day

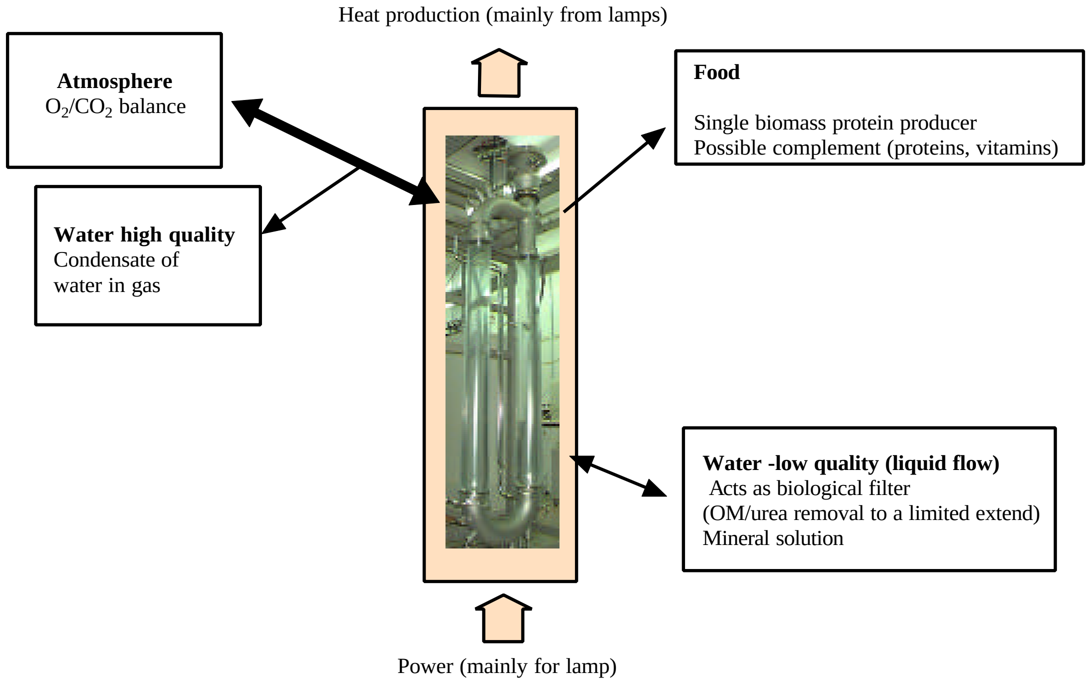
Instrumentation :
Probes : CO_2, O_2, pH, Temperature
Mass flow controler (gas/liquid)
Gas and liquid circuit (filters, pipes…)

Control /regulation

Control of productivity: Light
Dilution rate
pH regulation
Light regulation
Biomass (productivity) regulation

Notes

The system is sufficient for oxygen supply of 6 rats, i.e. about 11 % of the daily requirements of 1 person.



Integration and interrelation with other subsystems

The Spirulina photobioreactor is associated to 3 of the 4 mains function of a ALSS.

The Spirulina photobioreactor must be integrated into :

- The food production subsystem
- The water recycling and regeneration subsystem
- The atmosphere – O_2/CO_2 exchange - subsystem

UAB Spirulina PBR subsystem characteristics							
	Mass kg	Resupply mass/ Consumables (kg.week^{-1})	Volume m^3	Resupply volume/ consumable (m^3.week^{-1})	Power kW	Cooling kW	Maintenance h.week^{-1}
Reactor	77	?	77	?	?	?	?
Reactor specific elements (lamps,…)	?	?	?	?	6	6	
Instruments (control/probes/regulation..)	?	?	?	?	?	?	?
Miscellaneous	?	?	?	?	?	?	?

Table 8 : UAB PBR characteristic values. (template must be completed)

Such an approach must be made for each MELiSSA compartment. The UAB pilot compartment of the MELiSSA demonstration plant can be used. It must be kept in mind that we are yet only able to analyse ground system.

Table 8 has been made in a similar way to tables 6-4 and 7-3. The ressuply/consummable item are the item for replacement (maintenance) and for operating the system (as quantities of acid/base to maintain pH value).

It can noticed that the PBR detailled here is about the one required in the LSS designed and simulated for one person in ASAE Paper 2000-01-2380 (Poughon , 2000). Then by developing the same data for the other compartments of MELiSSA, an analysis including performances, closure and size (physical size and ESM size) could be done for this MELiSSA loop baseline LSS.

III.5 ESM : Conclusion

ESM methodology enables to synthesise the information into one single value. It is then easier to compare systems options (ESM-metric approach). On the other hand it is perhaps a too short simplification of complex systems such as LSS.

The calculation of crew time as a part of ESM seems a critical point as it can introduce important variations in the calculation of ESM.
We believe it is preferable to associate the crew time as a separate information to the ESM calculation.

Other important elements for the comparison of LSS option are the reliability and the closure of the system, which implicitly suppose that the interrelations between susbsystems (or compartment) and the mass balance analysis of the LSS were made.

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Food	# of Servings	Food	# of Servings	Food	# of Servings
Barbequed Tempeh Sandiwich	1	Melon Ginger Salad	2	Soysage	2
BBQ Seitan	0.36	Marinated Broccoli	1	Fresh Spinach & Mushroom Crouton Salad	1
Beets and Carrots in Lime Vinagrette	1	Marinated Tofu Appetizer	1	Spaghetti	1
Breaded Tofu Appetizer	1	Marinated Vegetable Salad	1	Sweet Potato and Red Pepper Homefry	1
Broccoli Pepper Salad	0.76	Melon Drink	1	Spicy Thai Style Noodle	0.35
Broiled Zucchini with Herbs	0.13	Mushroom Duxelles Spread	1	Spicy Oven Fries	1
Carrot Cookies	1	Mushroom Burger	1	Sweet Potato Salad	0.36
Carrot Drumsticks	1	Mushroom Medley	1	Sweet Potato Poundcake	2
Carrot Juice	0.62	Mushroom and Lentil Sandwich	1	Sweet Potato and Peanut Soup	1
Carrot Rice Loaf	1	North African Pizza	0.23	Spinach Side Dish (Tomato)	1
Carrot Soup	1	Orange Soy Yogurt	2	Summer Salad With Melons and Strawberries	1
Chocolate Soy Candy	1	Peanut Maple Topping for Pancakes	2	Strawberry Rice Drink	1
Chocolate Orange Rum sauce	1	Potato Onion Bread	0.33	Strawberry Sorbet	1
Cinnamon Peanut Rolls	2	Potato and Fresh Corriander Dish	1	Strawberry Topping	2
Coleslaw	1	Potato Salad	1	Stuffed Chard with Carrot Sauce	1
Creamy Herb Dressing	0.81	Peanut-Wheat Burger	0.40	Tarragon Sweet Beans, Onions and Potatoes #1	1
Creamy Onion Soup	1	Peanut Wheat Cereal	2	Tarragon, Sweet Beans, Onions and Potatoes #2	1
Dill Potatoes	1	Quick cream of mushroom soup	1	Tofu Custard Pie	1
Fatima Salad with Potatoes	1	Rice Amazake Pudding	1	Tofu Spinach Pie	1
Gado Gado with Peanut Dressing	1	Rice Milk	0.38	Tomato Cucumber Salad	1
Garden Style Stuffed Potatoes	1	Rice and Wheat Pancakes	2	Tomato Juice	1
Garlicy Scalloped Potatoes	1	Roasted Veggie Pizza	1	Tomato Lime Soup	1
Green Beans & Carrots in Tomato Sauce	0.87	Savory Herb Cracker	1	Tunisian Salad	1
Green Soybeans	1	Scalloped Potatoes and Carrots	1	Vichyssoise Cold Potato Soup	1
Greek Spinach Rice Balls	1	Scrambled Tofu	2	Roasted Veggie Sandwich	1
Herb Biscuits	0.67	Shiitake Consome with Greens	1	Vegetable Paella	1
Hot Wheat and Amasake Cereal	2	Sloppy Joe Tempeh	1	Veggie Salad with Snow Peas	0.89
Herbed Tofu Spread	1	Soybean Loaf	0.33	Wheat Amazake Waffles	2
Kale Soup	1	Soy Vanilla Pudding	1	Watercress and Sprouts	1
Lancashire Hot Pot	0.51	Soy Wheat Crepes	2	Wheat Berry and Rice Cereal	2
Lemon Poppy Seed Cake	1	Soya Mocha Beverage	1	Whole Wheat Amazake Bread	1
Lentil Loaf Sandwich	1				

Appendix A : Selected foods in the optimized menu. The number of servings refers to the number of servings for a single crew member within the 10-day menu cycle. Since integer programming was not used, rational numbered servings would be handled by serving the a full serving of the item over a period longer than the 10-day menu cycle. From Cloutier et al. (2000)

Appendix B : Henges and Ruminsky (2000) : 10 day cycles menus on the basis of the 15 crop selected as baseline diet for ALS programms by NASA.

	Day 1	Day 2	Day 3
Breakfast	Scrambled Eggs Cinnamon Sunrise Toast Instant Coffee, powder	Extruded Cereal Okara Granola Soy milk	Sweet Potato Pancakes Soy milk Instant Coffee, powder
Snack	Soft Pretzels Fruit Flavored Drink, dry		
Lunch	Vegetable Chowder Hearty Loaf Okara Granola Clusters Fruit Flavored Drink, dry	TLT Sandwiches Coleslaw Dried Peaches Fruit Flavored Drink, dry	Hearty Noodle Soup White Bread Swiss Chard, boiled Sweet Potato Fries Fruit Flavored drink, dry
Snack	Extruded Snack	Pinto Bean Dip Tortilla Chips Fruit Flavored Drink, dry	Peanuts, roasted
Dinner	Okara Patties Baked Beans Tomatoes Rockefeller Bread Pudding Instant tea, unsweetened, powder	Vegetable Stir-Fry w/Tempeh Brown Rice Okara Granola Clusters Instant tea, unsweetened, powder	Veggie Wraps Crunchy Confetti Salad Rice Pudding Instant tea, unsweetened, powder

	Day 4	Day 5	Day 6
Breakfast	Carrot Hashbrowns White Toast Jelly Instant Coffee, powder	Extruded Cereal Sweet Potato Minimuffins Soy milk Instant Coffee, powder	Okara & Whole Wheat Pancakes Soy milk Instant Coffee, powder Dried Apricots
Snack	Soft Sugar Cookies Soy milk		
Lunch	Soybean Ragout Brown Rice Soft Sugar Cookies Fruit Flavored Drink, dry	Tomato and Bacon Pasta Spinach, boiled Chess Pie Fruit Flavored Drink, dry	Thin Crust Veg Pizza Sweet Potato Pudding Fruit Flavored Drink, dry
Snack	Extruded Snack	Chess Pie	Soft Pretzels Tomato & Basil Salad
Dinner	Linguini w/ Fresh Tomato & Basil Sauce Green Salad Silky Salad Dressing	Tempeh Cacciatore Pasta Spinach Salad w/Italian Tofu Dressing Italian Croutons Carrot Cookies Instant Tea, unsweetened, powder	Tempeh Soft Tacos w/Sour Cream Greek Spinach Rice Balls Sweet Potato Pudding Instant Tea, unsweetened powder

	Day 7	Day 8	Day 9
Breakfast	Plain Bagel Jelly Extruded Cereal Soy milk Instant Coffee, powder	Scrambled Eggs Extruded Cereal Whole Wheat Toast Soy milk Instant Coffee, powder	Extruded Cereal Dried Peaches Soy milk Instant Coffee, powder
Snack	Carrot Cookies Soy milk		Spicy Baked Chips Fruit flavored drink, dry
Lunch	Super Chili Spinach Bread White Cake Fruit Flavored Drink, dry	Lentil and Spinach Soup Roasted Red Potatoes Fruit Flavored Drink, dry	Spicy Tofu Nuggets Baked Potato w/fixings Spinach, boiled Fruit Flavored Drink, dry
Snack		Extruded Snack Pinto Bean Dip	
Dinner	Florentine Sauce Pasta Spinach Bread White Cake Instant Tea, unsweetened, powder	Tofu Stir-Fry Brown Rice Chocolate Pudding Instant Tea, unsweetened, powder	Turtle Shells Green Salad White Bread Instant Tea, unsweetened powder

	Day 10
Breakfast	Extruded Cereal Cinnamon Sunrise Toast Dried Apricots Soy milk Instant Coffee, powder
Snack	
Lunch	Cream of Potato and Spinach Soup Marinated Tomato & Onion Salad Cinnamon Sunrise Bread Fruit Flavored Drink, dry
Snack	Chocolate Pudding Pie
Dinner	Okara Meatloaf w/ carrots and gravy Garlic Mashed Potatoes Chocolate Pudding Pie

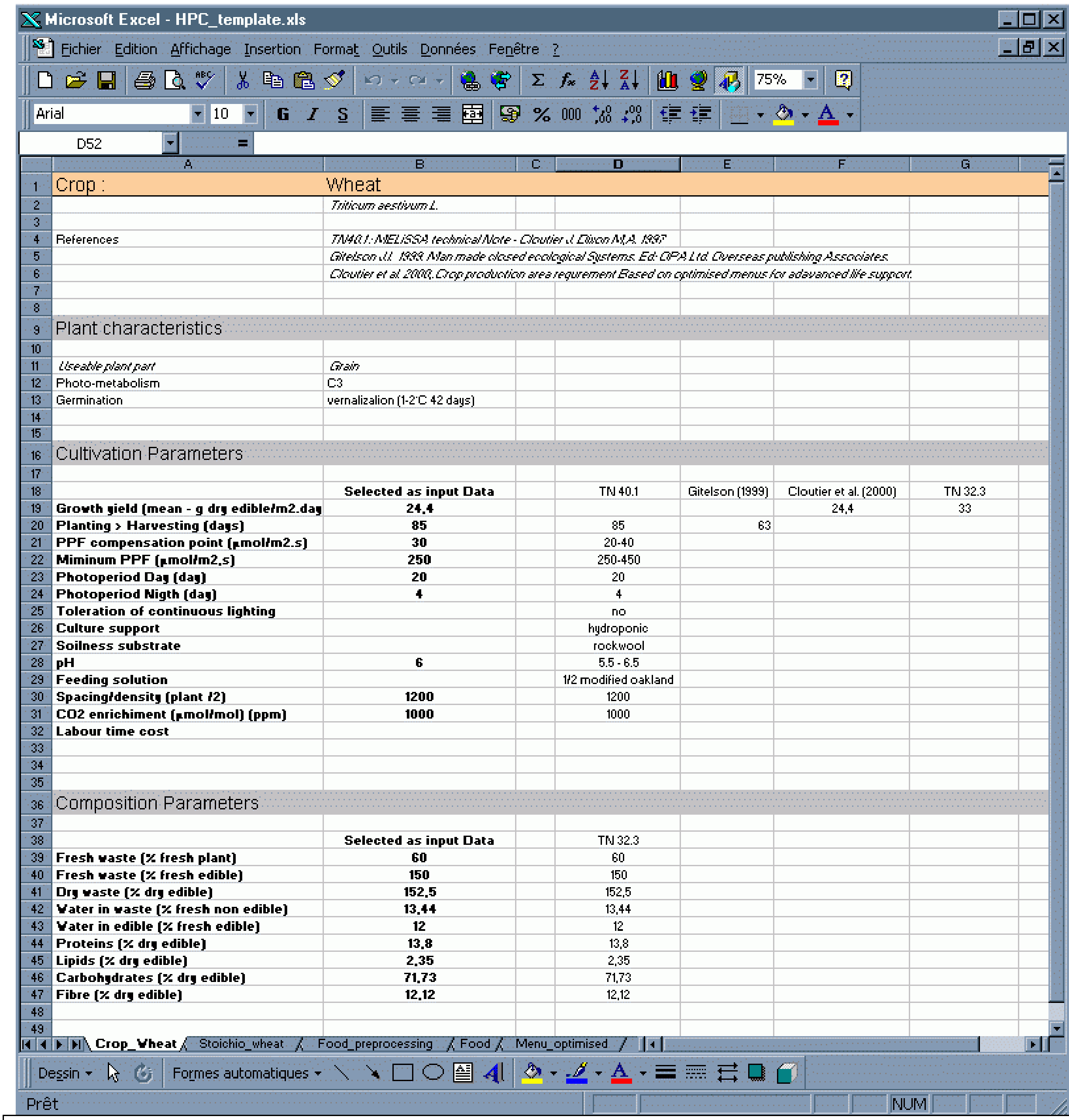
Appendix C : Review of main crop models developed for agricultural and ecological studies.

Model name	**Plants**	**Description**
Soybean and Wheat Growth Models of Sinclair . et al., 1986)	Soybean Wheat	Mechanistic models that examine how temperature, rainfall and solar radiation impact soybean crop yields. The models use daily weather data (solar radiation, minimum and maximum temperatures and precipitation) to predict daily leaf area index, biomass accumulation, seed growth and seed weights.
CERES-Maize (Crop Environment Resource Synthesis)		Predictive, deterministic model designed to simulate corn growth, soil, water and temperature and soil nitrogen dynamics at a field scale for one growing season. It is related to other CERES models, such as the CERES-Wheat model. The model is used for basic and applied research on the effects of climate (thermal regime, water stress) and management (fertilization practices, irrigation) on the growth and yield of corn. It is also used to evaluate nitrogen fertilization practices on nitrogen uptake and nitrogen leaching from soil and in global change research to evaluate the potential effects of climate warming and changes in precipitation and water use efficiency due to increased CO2. Potential dry matter production is calculated as a function of radiation, leaf area index and reduction factors for temperature and moisture stress. Six phenological stages are simulated, (based primarily on degree-days), and leaf and stem growth rates are calculated (depending on phenological stages). Available photosynthate is initially partitioned to leaves and stems, and later for ear and grain growth. Any remaining photosynthate is allocated to root growth. However, if dry matter available for root growth is below a minimum threshold, grain, leaves and stem allocations are reduced and the minimum level of root growth occurs. Separate routines calculate water balance, including runoff, infiltration, saturated and unsaturated water flow and drainage. Mineral nitrogen dynamics and nitrogen availability for crop uptake are also calculated. The model provides information on above-ground dry matter, nitrogen content, grain dry matter and nitrogen content, summaries of water balance and soil mineral nitrogen. Data used as input include: climate variables such as latitude, radiation and daily temperature and precipitation; management variables such as sowing date, plant density, irrigation schedules; crop genetic constants, and, soil/site parameters such as soil albedo, and soil layer thickness.
CropSys		CropSys (Crop Systems) is a process-level, simulation model designed to predict the performance of multiple cropping systems across genotype, soil, weather and management combinations (Caldwell and Hansen, 1993). Use of a weather generator allows analysis of the stochastic performance of the systems. CropSys was designed by Robert Caldwell of the University of Hawaii as part of the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) program which is partially funded by USDA-CSRS. CropSys is a high-level modeling system that contains several sets of models, including several of the CERES-type models. The

		models currently in CropSys include CERES-Barley, CERES-Maize, CERES-Millet, CERES-Rice, CERES-Sorghum, and CERES-Wheat. The SOYGRO model is also part of CropSys. CropSys uses output files defined within the IBSNAT Decision Support System for Agrotechnology Transfer (DSSAT).
GLYCIM		GLYCIM is a dynamic simulation model with hourly time steps. It predicts growth and yield of a soybean crop in response to climate, soil and management practices by deterministic simulation of organ-level processes such as photosynthesis, transpiration, carbon partitioning, and organ growth and development. The model was developed by Acock and Trent (1991). The model requires daily maximum and minimum temperature, precipitation and solar radiation data as input. Soils data are also required to execute the model (e.g. soil horizons, organic matter and nitrogen content). The model is designed for hourly time steps for a growing season. The model is executed for a single typical plant in a canopy.
SWHEAT		SWHEAT (Spring WHEAT) is a version of WHEAT. SWEAT is a mechanistic, process oriented, point model (Baker et al., 1981). The model is designed specifically to examine the effects of salinity on crop production. Its purpose is to predict how changes in salinity will affect spring wheat yields. The model uses as input: daily maximum and minimum temperature, soil variables, solar radiation, wind speed, vapor pressure and nitrogen content data. The model provides output on dry matter production and grain yield. The model uses daily time step over a season.
BEANGRO, SOYGRO and PNUTGRO (acronym : CROPGRO)		BEANGRO, SOYGRO and PNUTGRO comprise a group of related legume production models (Hoogenboom et al., 1992). They are deterministic and mechanistic models which simulate physical, chemical, and biological processes in the plant and related environment. Their purpose is to predict crop yields and related agronomic parameters. The models are constructed to simulate primary plant processes as a function of weather, soil, and crop management conditions. The model input data requirements are: daily weather data (air temperature, precipitation, solar radiation); soil physical conditions of the profile by layer; soil chemical conditions of the profile by layer (nitrogen only); and crop management conditions (planting date, spacing, irrigation management). The models predict the weight of leaves, stems, roots, pods, shells, seeds, LAI (leaf area index), and root length density on a daily basis. They also predict main phenological events such as flowering and maturity.
GOSSYM/COMAX		GOSSYM/COMAX is a cotton growth model and expert system. The model is a mechanistic model that simulates cotton growth given weather, soil and management practices. Management options include fertilizer and irrigation strategies. Model data input requirements include soil moisture and bulk density for each soil horizon and weather data (including temperature, wind speed, solar radiation and humidity). Model output includes plant height, water stress/day, nitrogen stress/day, soil temperature and soil water potential. The model operates on daily time steps and calculates material

		balances for water and nitrogen
GOYCIM	Soybean	GOYCIM is a soybean simulation growth model that is an extension of GLYCIM. Its purpose is to predict how soybeans will grow given weather, soils, and management strategies. It differs from GLYCIM in that GOYCIM is designed to be run on larger scales (counties to regional). GOYCIM simulates photosynthesis; transpiration; carbon partitioning; organ growth and development; water movement; plant response to temperature and soil moisture. The model operates on a daily time step for a growing season. A typical run is for 20 years. The model runs on a Macintosh, PC or Cray computer. Model input data requirements include: daily maximum and minimum temperature, rainfall, wind run (if available), wet and dry bulb temperature (if available), soils data (e.g. depth, texture, bulk density, water content, nitrogen content), crop management strategies, latitude, CO2 concentration and solar radiation. Model output contains over 25 variables related to plant yield, nitrogen fixation, carbon storage per plant component and leaf area index.
QB-Maize		QB-Maize (Quick Basic) is a simulation model similar to other crop growth models that model plant growth processes. With QB-Maize, an attempt has been made to simplify plant growth and development processes. The model was developed by Tom Sinclair at the ARS/University of Florida. The model has several components: input subroutines, leaf growth, carbon budget, seed growth, and water budget subroutines. The model requires meteorological inputs consisting of daily maximum and minimum temperatures, precipitation and solar radiation. Agronomic input includes planting date and population data. Model output includes leaf area index (LAI), evapotranspiration, dry matter and grain mass. The model uses a daily time step. It models plants at the plot scale.
2DLEAF		The model simulates the processes of CO2, O2, and water vapor diffusion in an intercellular space and boundary layer, evaporation from cells' surface, assimilation of CO2 on cells surface, and stomatal movements. The model purpose is to predict the leaf photosynthesis and transpiration for various environmental conditions for plants adapted and non-adapted to elevated CO2 atmosphere. The model uses a unique approach to leaf growth in that each leaf's cross section is mapped onto a grid and each point is given certain properties. Two dimensional diffusion equations using Farquhar's formula are used.
SUBSTOR-Potato V2.0	Potato	Modelled on a single plant basis and converted to mass per m2 of soil area for leaves, stems, tubers and roots, leaf area index, aboveground dry biomass at maturity, tuber weight at maturity, tuber yield (kg ha-1). Crop nitrogen content, nitrogen concentration in the tuber plant nitrogen content at maturity, tuber nitrogen content at maturity.

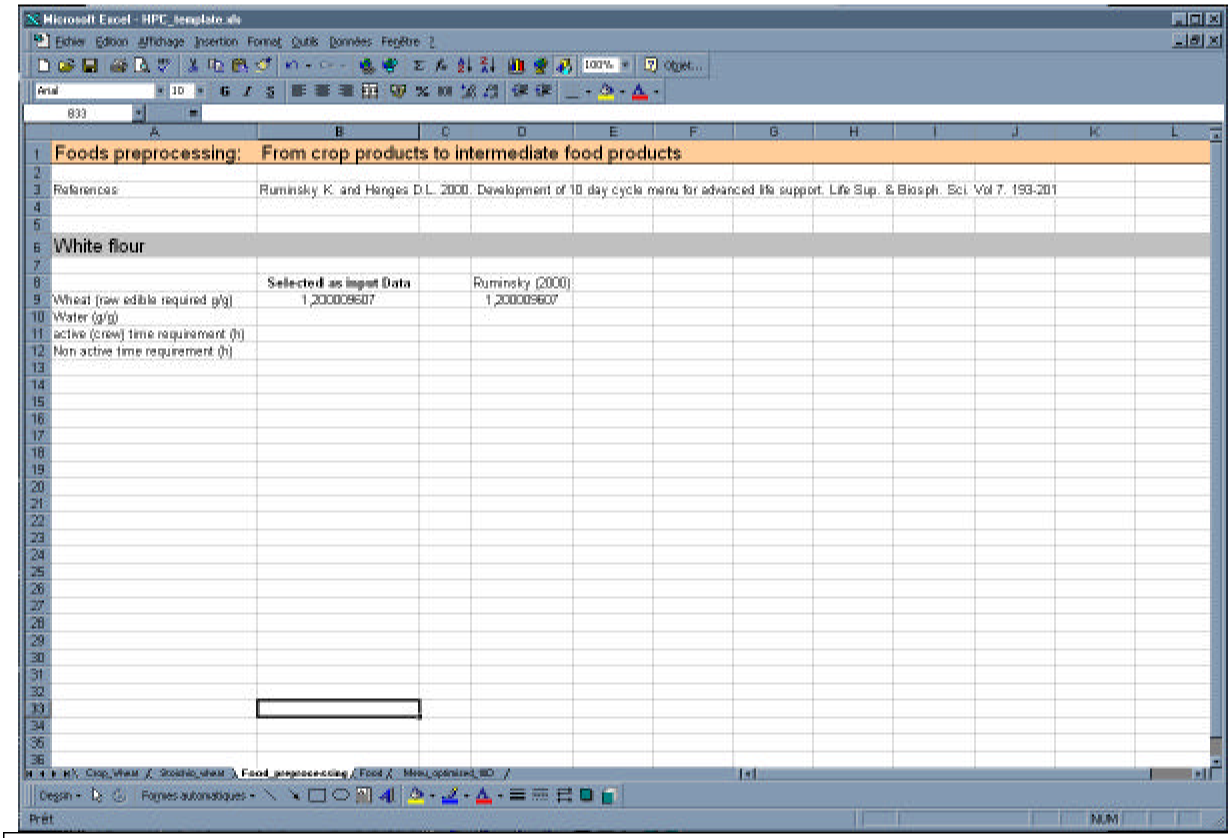
Appendix D : Proposition of a template for compiling and sorting data for plants, food processing and food, and for their use for “menu based” optimisation”



	A	B	C	D	E	F	G
1	Crop :	Wheat					
2		*Triticum aestivum L.*					
3							
4	References	*TN40.1: MELiSSA technical Note - Cloutier J. Dixon M.A. 1997*					
5		*Gitelson J.I. 1999. Man made closed ecological Systems. Ed: OPA Ltd. Overseas publishing Associates.*					
6		*Cloutier et al. 2000. Crop production area requirement Based on optimised menus for adavanced life support.*					
7							
8							
9	Plant characteristics						
10							
11	*Useable plant part*	*Grain*					
12	Photo-metabolism	C3					
13	Germination	vernalizalion (1-2°C 42 days)					
14							
15							
16	Cultivation Parameters						
17							
18		**Selected as input Data**		TN 40.1	Gitelson (1999)	Cloutier et al. (2000)	TN 32.3
19	**Growth yield (mean - g dry edible/m2.day**	**24,4**				24,4	33
20	**Planting > Harvesting (days)**	**85**		85	63		
21	**PPF compensation point (µmol/m2.s)**	**30**		20-40			
22	**Miminum PPF (µmol/m2.s)**	**250**		250-450			
23	**Photoperiod Day (day)**	**20**		20			
24	**Photoperiod Nigth (day)**	**4**		4			
25	**Toleration of continuous lighting**			no			
26	**Culture support**			hydroponic			
27	**Soilness substrate**			rockwool			
28	**pH**	**6**		5.5 - 6.5			
29	**Feeding solution**			1/2 modified oakland			
30	**Spacing/density (plant /2)**	**1200**		1200			
31	**CO2 enrichiment (µmol/mol) (ppm)**	**1000**		1000			
32	**Labour time cost**						
33							
34							
35							
36	Composition Parameters						
37							
38		**Selected as input Data**		TN 32.3			
39	**Fresh waste (% fresh plant)**	**60**		60			
40	**Fresh waste (% fresh edible)**	**150**		150			
41	**Dry waste (% dry edible)**	**152,5**		152,5			
42	**Water in waste (% fresh non edible)**	**13,44**		13,44			
43	**Water in edible (% fresh edible)**	**12**		12			
44	**Proteins (% dry edible)**	**13,8**		13,8			
45	**Lipids (% dry edible)**	**2,35**		2,35			
46	**Carbohydrates (% dry edible)**	**71,73**		71,73			
47	**Fibre (% dry edible)**	**12,12**		12,12			
48							
49							

Sheets: Crop_Wheat / Stoichio_wheat / Food_preprocessing / Food / Menu_optimised

CROP DATA SHEET



FOOD PROCESSING DATA SHEET