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The LUNAR LABORATORY - An attractive Option for the next Phase of Lunar Development

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Abstract

The proposal of *returning to the Moon to stay* was made by President Bush in July 1989, but the changes in the geopolitical environment since the end of the cold war have prevented a serios discussion of this proposal until now. It is expected, however, that this question of a permanent installation on the Moon will come up early in the next decade. Thus concepts and plans have to be ready by that time to be discussed and evaluated. This report describes in detail a *Lunar Laboratory* that is supposed to grow from about 20 to 100 people in 50 years. Some 1500 metric tons of facilities and equipment are needed on the Moon. Average crew duty cycles are assumed to be 6 months. A lunar space transportation system is proposed that is comprised of a heavy lift launch vehicle, a lunar ferry vehicle and a space operations center in lunar orbit. The systems behaviour, the dynamics of selected parameters and the overall performance and cost-effectiveness of the lunar laboratory are analysed and presented. It is shown that the average annual cost of a lunar man-year are less than 40 million (1993/94) dollars and that the average annual operations cost of this lunar base are less than 3 billion. The results are summarized in 19 tables, 7 figures and two appendices with the computer models, comprising 65 pp.

Table of Contents

1. Introduction	page 1
2. Program Structure	3
3. Lunar Laboratory Size and Logistic Requirements	4
4. The Space Transportation System Supporting Logistically the Lunar Laboratory	5
5. Inputs, Outputs and Performance of the Lunar Laboratory	9
6. The Acquisition of the Lunar Laboratory	12
7. Program Cost	17
8. Specific Costs of Lunar Products and Services	24
9. Cost Summary and System Effectiveness	28
10. Summary and Conclusions	32
References	35
Appendix 1 : Lunar Laboratory Model Assumptions (LUBSIM)	page A 1 - 11
Appendix 2 : Inputs to the Space Transportation Simulation Model (TRASIM)	A12 - 27

List of Tables and Figures

Table 3-1: Typical Growth of lunar crew and facilities
Fig. 3/1 : Development trends of the total lunar population and the lunar science crew during the 50 year life-cycle
Table 4-1: Typical lunar laboratory growth on the planned flight schedule for support of the lunar laboratory using 100 % reliability
Table 5-1: Projected outputs of early lunar facilities based on their theoretical mass growth rates
Figure 5/1: Comparison of lunar facility mass and annual output of all products
Table 5-2 : Projected theoretical imports required by the operational lunar laboratory on the lunar surface as projected by the model
Figure 5/2 : Development trends of lunar products for lunar use and the mass of imports to the lunar surface
Table 6-1: Initial Program Development Schedule
Table 6-2: Detailed quarterly flightplan for the acquisition period
Table 6-3: Manifest for HLLV and LUBUS flights
Table 7-1: Non-recurrent cost of lunar laboratory
Figure 7/1 : Distribution of expenditures for development and testing of the elements comprising the lunar laboratory project (space transportation system and lunar facilities
Table 7-2: Direct operating cost of lunar laboratory
Table 7-3: Overview of sustained engineering, production, operations and total cost during the operational phase
Table 7-4: Overview of space vehicle direct operations cost of primary flights and specific transportation costs of cargo and passenger transportation during the operational phase
Figure 7/2: Mission cost for passengers and cargo
Figure 7/3: Specific recurrent transportation cost for passengers (upper curve - million 1990 $/seat) and for cargo (lower curve - million 1990 $/metric ton delivered to the Moon)
Table 7-5 : Overview of total transportation system cost with prorating production cost and up-front cost equally over the operational years operations and total cost during the operational phase (million 19903/94 $)
Table 8-1: Specific direct costs of lunar products and services excluding their share of logistic costs,financing and profit.

Figure 8/1: Comparison of specific cost of lunar products with the specific transportation costs of Earth-lunar cargo delivery
Table 8-2: Theoretical specific direct costs of lunar products and services including their logistic logistic burden (at Lulox cost of 0.6 m $/t), but not the cost financing and profit.
Figure 8/2: Trend of specific cost of transportation of imports and production of lunar oxygen.
Table 8-3: Projected total annual sales potential (million $ p.a.)
if the total transportation cost are charged to the lunar operator
Table 9-1 : Lunar Laboratory life-cycle cost summary (million 1993/94 $)
with 10 + 50 year life-cycle
Table 9-2 : Lunar laboratory system operational life-cycle cost trends
with up-front cost prorated over operational life-cycle
Figure 9/1: Lunar Laboratory Sytem total cost trend with development cost and production costs amortized over
the fifty year operational life cycle
Table 9-3: Development trends of primary system-effectivness ratios
Table 9-4: Life-cycle performance and cost summary of a lunar laboratory program
Table 10-1: Comparison of the economic performance of the Lunar Laboratory with alternative Lunar Outpost Options
Figure 10/1: Reduction of average annual public funds for the operation of the lunar laboratory as a function of utilization of the available lab spaces by commercial customers and of the yield per lab space in terms of million $ for a six month period on the Moon including transportation of one person

1. Introduction

The first phase of lunar development ended with the flight of APOLLO 17 to the Moon in December 1972. The primary reason for ending the first phase of lunar development was the Vietnam war requiring all available resources of the United States, 100 billion dollars at the peak of this engagement! But it was also determined, that - after achieving the political objective of being there first - the relatively poor cost-effectiveness of the APOLLO program in exploring the resources of the Moon was not justifying more lunar excursions of this type.

The seventies saw a space program concentrating on the development of Earth satellites and a new space transportation system, the partly reusable Space Shuttle. This space vehicle was designed for transportation jobs to the low Earth orbit with the intention to replace all expendable systems. The unfortunate loss of the CHALLENGER vehicle changed all this and caused a big gap in the American space program. Also, it was of no help to revive any plans for a continuation of the lunar exploration program.

In the early eighties some interest developed again in returning to the Moon in connection with feasibility studies of Space Solar Power Systems (SSPS). Lunar resources were found to be an attractive means to reduce the cost of constructing solar power plans in GEO[1,2,13] . Also the US Congress demanded in the mid-eighties an answer to the question of how the space program should continue. A *National Commission On Space* made a positive recommendation to return to the Moon among other space programs[3]. Other studies underlined this recommendation in those years [4,5,6,7,9,11].

The result of these efforts was the recommendation of President Bush in Juli 1989, 20 years after the first landing of men on the Moon, to return to the Moon to stay. However, three months later, the Berlin wall broke down and the dissolution of the Sowjet Union began leading to the end of the cold war. All space programs suffered from this upheavel of the geopolitical scene and most of them were put on the back burner as the consequence of changing priorities[15].

In the mid 90s the European Space Agency expressed an interest to take up lunar exploration after some lunar probes of Japan and the United States were quite successful[14]. Thus it is encouragement enough to discuss again the pros and cons of returning to the Moon and establishing a permanent facility on the lunar surface. This planning activity is sponsered also by the International Academy of Astronautics, which re-activated its Subcommittee on Lunar Development[16]. Several national and international symposia took place during the last decade to discuss various aspects of robotic and human exploration of the Moon in the future. A great deal of the information available has been compiled in a Lunar Data Base[17].

The presently recognized objectives of continuing the exploration and utilization of lunar resources have been summarized as follows[9,16]:

Genuine (primary) objectives of a lunar base:

1. Provide a science laboratory in the unique environment of the Moon.
2. Improve our knowledge of the Moon and its resources.
3. Produce marketable services and space products on the Moon.
4. Establish the first extraterrestrial human settlement.
5. Contribute to the supply of the Earth with space based energy.
6. Provide a focus for the development of space technology.
7. Demonstrate the potential growth beyond the Earth.
8. Enhance the evolution of the human culture into space.
9. Provide a survival shelter in case of a global catastrophe.
10. Provide reliable space transportation systems to the Moon.
11. Provide an isolated depository for high level wastes in case of need.

Secondary objectives of a lunar base:
(these could also be achieved or supported by other than space programs)

1. Improve the understanding and control of Planet Earth.
2. Stimulate the development of advanced technologies on Earth.
3. Provide opportunity for international cooperation.
4. Provide rewarding job opportunies.
5. Assist in reducing tensions and conflicts on Earth.
6. Provide the infrastructure and experience for global enterprises.
7. Provide opportunity for involvement in frontier activities.
8. Provide a peaceful outlet for the military-industrial complex.
9. Contribute to the national prestige of participating nations.
10. Improve our understanding of our solar system.
11. Improve our understanding of the universe.

Thus one has to bear in mind, that lunar activities will - in most cases - help to achieve several of the identified objectives listed above. They will change their relative priorities as function of time, depending on the current state of the planet. While a decision to go back to the Moon with people can not be expected in this decade, it may become an issue shortly after the turn of the century[15].- Now is the time to develop attractive options for a new phase of lunar development so that politicians have a choice of alternatives to select from, if and when a decision is due. It is obvious that the key question is that of transportation of people and supplies to the Moon, because there is no lunar space transportation available at present or in sight. But new space transportation systems have to be matched to program size and objectives, consequently the size and life-cycle of potential lunar bases are important factors determining the overall program. *To make this relationship transparent is the primary purpose of this report.*

This analysis begins with discussing the ground rules adopted for developing the program structure, limiting the size and logistic requirements of a lunar base. Then the lunar space transportation system is selected and described, to be followed by a cost analysis of the entire program, selected as one of the better options for the next phase of lunar development.

2. Program Structure

A lunar laboratory with built-in growth potential would be a logical choice to return to the Moon early in the 21st century with the goal to establish a permanent facility on the lunar surface to explore and exploit lunar resources for the benefit of humankind. This example of a lunar laboratory is planned on the basis of a 10 year development period a 50 year operational life-cycle and a lunar crew up to 100 persons. Its primary objectives are :
(1) exploration of the Moon, (2) research under lunar environmental conditions on and from the Moon, (3) pilot production experiments and (4) laying the foundation for further steps of lunar development .

Groundrules and assumptions:

1. - The first control variable is the number of laboratory spaces to be provided for experimenters involved in public and commercial research and development activities on the lunar surface. - This parameter starts out with only few working places in the early years growing to about 50 in the 50th year of the life-cycle in the selected scenario.

2.- The second control variable is the length of the duty cycle per crew member, determining the rotation frequency of the lunar crew The average duty cycle for lunar crew members in this science oriented enterprise is planned to be about six months due to its experimental character. It impacts heavily the launch rate of the passenger vehicle serving the lunar facility and therewith the system cost.The duty cycle is thus an important variable and it could be increased if demanded by the actual requirements of a certain activity phase during the acquisition to cut down on flight number and cost.

3. - The third control variable is the mass of lunar products to be produced anually by lunar facilities. - Typically, the production begins in the first year of the life-cycle processing lunar soil at the rate of a few thousand metric tons per year producing lunar oxygen and some raw materials. This production activity is growing during the life-cycle requiring up to about ten thousand metric tons of lunar soil p.a. with increasing utilization rates of the lunar soil input.

4. - In this scenario it is further assumed that nearly all the oxygen propellants for the lunar landing and launch vehicle (LUBUS) will be produced on the Moon. The return propellants of the HLLV payload stage will use Earth propellants, however. Some liquid oxygen has also to be imported during the first years to the lunar orbit service station(LUO-SOC) by tanker flights from the

Earth because the production of lunar oxygen will initially not cover all of the requirements. This assumption is a compromise, adopted with the intent of increased crew safety, not to overload the production facilities, to keep the operation as simple as possible and keep the cost down. Hydrogen propellants are delivered from the Earth by the HLLV throughout the life-cycle to lunar orbit for refueling the lunar launch- and landing vehicles(LUBUS) at the lunar orbit space operations center. This LUO-SOC, a modified second stage of the HLLV, is prepared for its mission in LEO, transfered to LUO by its own propulsion, and will be operational before the first lunar crew arrives at the lunar base site.

A preliminary mass model of the lunar base proper must be derived first to determine the logistic requirements. An iterative matching process will follow until a balance is achieved between the capabilities of the space transportation system, the requirements of the lunar facility and the resources considered available for such an enterprise.

3. Lunar Laboratory size and logistic requirements

A lunar base simulation model (LUBSIM)[1] was used for deriving relevant development trends versus time for the life-cycle planned for the lunar laboratory envisioned. This parametric model calculates an incremental annual growth of the respective facilities for the life-cycle planned, which is caused by the equations introduced. In reality however, these facilities will grow in a step-function initially, because whole modules are transported to the Moon in the beginning of the acquisition period. This has be done within the capabilities of the transportation system and the available human labor at the base site.This detailed annalysis is part of the acquisition planning discussed in chapter 6.

Table 3-1: Typical Growth of lunar crew and facilities (metric tons)
Numbers in ( ) indicate the individual facilities of the model summarized as a group .

year	lunar science crew p.a.	total lunar crew p.a.	laboratories &scientific equip.	habitat + farm elements (17 + 18+19)	pilot prod.fac & equip. (01-06,09)	infrastructure facility & equip. (10-16)	total lunar facilities	actual annual facility & equip. growth	desired lunar power installed (kW)
1	2	27	11	175	95	155	434	434	991
2	4	33	24	191	130	195	531	97	1433
3	7	35	36	197	142	203	580	49	1730
4	9	40	49	211	161	216	638	58	2036
5	12	42	61	220	168	218	668	30	2187
10	20	52	90	291	188	230	794	av.25	2786
15	27	63	132	348	199	241	920	av.25	3324
20	35	74	165	421	205	251	1047	av.25	3864
30	45	90	208	535	215	274	1235	av.19	4798
40	50	98	228	615	223	289	1356	av.12	5569
50	50	100	228	652	230	297	1408	av.5	6116
tot.	1785	3800							
av.	37	76						28	4187

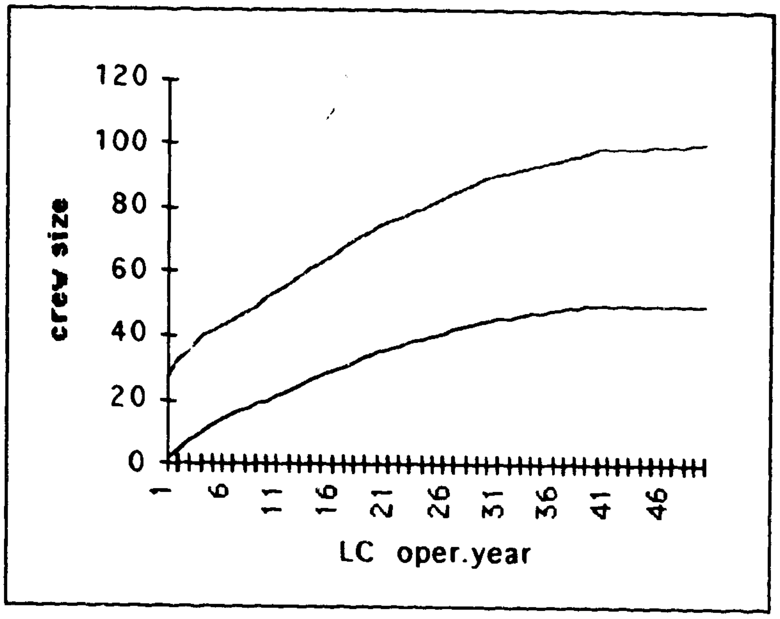

Fig. 3/1 : Development trends of the total lunar population(upper curve) and the lunar science crew(lower curve) during the 50 year life-cycle

This frame of reference for the crew size and the mass of the lunar facility is the basis for selecting a suitable space transportation system. This has to be sized and structured with respect to performance and capacities before a detailed analysis of the input- and output mass flows of the lunar laboratory can be discussed in detail. This in turn will lead to a modification and final design of the space vehicles involved.

4. The space transportation system to support logistically the lunar laboratory

The governing factor for the acquisition process and operation of the lunar laboratory specified above is the payload capability and launch rate of the **lunar space transportation system (LSTS)** to be employed. It determines the growth rate of the lunar laboratory, but also to a great extent the amount of manual labor required to put the facilities on the Moon in operation. Logistics cost is the major cost item of the entire life-cycle system cost.

Generally, pre-fabricated modules with large dimensions and masses transported to the Moon are preferred, because they lead to reduced requirements of expensive human labor on the Moon. On the other hand, if the flight frequency is less than four flights p.a. then the operational flexibility would suffer. Furthermore it must be assured that enough reserve payload capability for unforseen emergencies will be provided. For all these reasons, the new lunar space transportation system must be defined first. All of these factors have to be taken into consideration in planning and selecting the space transportation concept.

The **logistic support system for the lunar laboratory** selected is a near state-of-the-art fully reusable space transportation sytem using chemical propellants only and available subsystems from the Shuttle and other existing programs[9,10]. Aside from spaceports on the Earth and the Moon, the lunar space transportation system (**LSTS**) is comprised of three elements :

(1) a heavy lift launch vehicle(**HLLV**) for passenger and cargo transportation between the Earth spaceport and a space operations center in lunar orbit,

(2) the space operation center (**LUO-SOC**) in a low lunar orbit (100 km), being used for the transfer of passengers and cargo payloads, but also as propellant storage and maintenance facility, and

(3) a lunar bus (**LUBUS**) for local transportation of passengers and cargo between the lunar spaceport and the LUO-SOC.

The **HLLV** has a nominal payload capability of **100 metric tons(t) to lunar orbit** and of about 50 t on a direct flight to the lunar surface using its third stage to land the cargo. This payload capability is the average performance during the entire life cycle. It would be somewhat lower in the beginning and probably grow during the life-cycle resulting from regular product improvement efforts, but the payload capability is kept constant to keep the model simple, an assumption that does not change greatly the overall life-cycle performance. This heavy lift launch vehicle, based on the NEPTUNE concept of the Aerospace Institute of the Technical University Berlin (developed during the last 25 years)[4,9,10], can either transport cargo or passengers to the lunar orbit. The passenger version has a 50 t crew cabin including **40 passengers** and 5 t for additional aerobrakes. It is attached to the 3rd stage and is capable of returning to the Earth from the LUO-SOC, for which 30 t return propellants are needed. It carries also 11 t of extra hydrogen required for the continuing flight of the LUBUS roundtrip between LUO and lunar base. This leaves a performance reserve of 9 t which could be used in due course of development for more luggage of the crew or priority supplies. The HLLV in its cargo version would carry a **70 t cargo** module, 15 t of return propellants and 15 t liquid hydrogen propellants for LUBUS operation.

These assumptions lead to the following mass- and performance characteristics on which the lunar landing- and launch vehicle has to be sized:
Charateristic velocity for a single flight between the lunar orbit and the lunar spaceport = 2000 m/s, exhaust velocity 4500 m/s, mass ratio (minimum) = 1.56 .

LUBUS Passenger Flights:

DOWN LEG of the LUBUS from LUO-SOC		
empty stage	20 t	
crew cabin with crew	**25 t**	**(40 passengers for 1 hr flight time)**
hydrogen for ascent	7 t	
stage at cut-off	52 t	
usable propellants required	30 t	(5 t LH_2 + 25 t Lulox)
take-off mass in LUO	82 t	

ASCENT of the LUS to LUO

empty stage mass	20 t	
cabin with crew	**25 t**	**(max.capacity 40 persons for 1 hr)**
Lulox for down leg	25 t	
cut-off mass	70 t	
usable propellants required	40 t	(6 t LH_2 + 34 t Lulox)
Take-off mass on the Moon	110 t	

Cargo flights:

DOWN LEG from LUO-SOC

empty stage mass	20 t	
cargo incl.packaging	**70 t**	
hydrogen for ascent	6 t	
cut-off mass on the Moon	96 t	
usable propellants required	57 t	(7 t LH_2 + 50 t Lulox)
Take-off mass in LUO	153 t	

ASCENT of Cargo-LUBUS

empty stage mass	20 t	
Lulox for down-leg	50 t	
cut-off mass	70 t	
usable propellants required	40 t	(6 t LH_2 + 34 t Lulox)
Take-off mass on the Moon	110 t	

Mass-balance HLLV Passenger flights with max. **40 Persons**: 50 t crew cabin + 30 t return propellants + 11 t hydrogen (without losses) = 91 t propellant reserves or additional supplies 9 t, possibly not available in the early years of operation. Total nominal LC average HLLV payload capability = 100 t delivered to LUO, used for nominal scenario = 91 t.

Mass-balance of HLLV cargo-flights : 15 t return propellants + 13 t + 2 losses hydrogen for LUBUS = 30 t propellants + **70 t Cargo** = 100 t total payload delivered to LUO, used as *nominal* payload capability for this scenario.

Lunar LOX-requirements at the lunar spaceport:
Passenger flights : 25 + 34 + 1 losses = **60 t per flight**
Cargo flights: 50 + 34 + 1 losses = **85 t per flight**

Earth LOX -requirements in LUO , if LULOX is not available
Passenger flights : 25 + 25 = **50 t** per flight in addition to 10 t LH_2 with losses.Cargo flights with 70 t down but 0 payload up : 50 + 10 = **60 t** LOX + 10 t LH_2 with losses.

The **LUO-SOC** has an empty mass of 250 **t** and is a modified second stage of the HLLV[10]. It transports itself during the first operational year in an extra flight to the lunar orbit, after modifications, refueling and checkout have been completed in low Earth orbit. Two secondary refueling flights to low Earth orbit (LEO) are required by the HLLV (this is a total of 3!) to make this transfer of the LUO-SOC facility into lunar orbit using its own propulsion system feasible.

This facility is scheduled to be in lunar orbit, before the first lunar crew arrives.Under standard operational procedures, the LUO-SOC has a crew of 3-6 depending on the traffic. A crew duty cycle of 3 to 6 months is anticipated.

The transfer to lunar orbit requires a velocity increment of 4080 m/s, this results with c = 4600 m/s in a mass ratio of 2.43. The LUO-SOC with a dry mass of 250 t arrived in LEO with 300 t propellants. After refueling 2 x 300 t in LEO its take-off mass is 250 + 900 = 1150 t . The mass ratio of 2.43 leads to a SOC mass at arrival in LUO of 1150 : 2,43 = 473 t or 250 t hardware, 23 t unusable residuals and **200** t of propellants for later use by the LUBUS.

Several **direct flights of the HLLV 3rd stage** to Earth will be needed during the acquisition phase of the lunar laboratory to transport the initial large facility modules to the lunar base site before the arrival of the first crew.These will be in addition to the regular schedule.
The third stage would have to undergo the following modifications for this purpose :
- enlargement of the propellant capacity by about 25% (from 215 to 270 t),
- change of the heat shields (no aerodynamic braking required),
- addition of a landing gear.

The mass and performance characteristics of this lunar landing stage would look approximately as follows:
Velocity requirement = 5900 m/s, exhaust velocity 4500 m/s, mass ratio = 3.70.

Initial mass in LEO	365.0 t
usable propellants	266.5 t
cut-off mass on the Moon	98.5 t
stage mass with 5 t residuals	53.5 t
net payload on the Moon	45.0 t

The empty stage would remain on the Moon and be available for storage of liquids and gases. Also the 5 t of residual propellants and gases after landing would be available for other use. The production cost including modifications of these stages which are on the order of 250 million $/unit would have to be included in the cost balance of the lunar facilities to obtain a complete picture.These three flights will be scheduled in the year before the first crew arrives on the Moon with the most critical facilities, such as the habitat,power plant and oxygen plant. These have to be at the lunar base site, checked-out and in operable condition to allow beneficial occupancy when the first crew arrives.

Matching annual launch rates with first approximation of requirements of the laboratory leads to the following preliminary payload capacities and propellant requirements:

Table 4-1: Typical lunar laboratory growth on the planned flight schedule for support of the lunar laboratory using 100 % reliability
(passenger flight = 40 persons, cargo flights = 70 t, one-way = 45 t + empty stage)
*) five flights tests, **) 4 Lubus delivered partly fueled to LUO,# tanker flights

YEAR	no.and capacity of pass. flights p.a.	no of regular cargo flights p.a.	extra cargo flights init. facil.	total cargo capacity rqrd.	flights to SOC fac.+ prop.	total no. of HLLV flights p.a.	Lox delivered to LUO from Earth	Lulox produced (no losses)	Lulox reqrd.
0	-	-	-	0	5*)2	7	200	0	0
1	1 = 40	2(70)	3(45)	275	2**)+2	11	100	125	0
2	2= 80	2(70)	2(70)	280	2**)	8	100	190	290
3	2= 80	2(70)	2(70)	280	2#	8	170	240	290
4	2= 80	2(70)	1(70)	210		5		290	290
5	2= 80	2(70)		140		4		310	290
sum1-5	9=360	10(700)	8(485)	1185	15	42	570	1155	1160
10	3=120	2		140		5		370	350
15	3=120	2		140		5		400	350
20	4=160	2		140		6		425	350
30	5=200	2		140		7		450	410
40	5=200	2		140		7		480	470
50	5=200	2		140		7		500	470
LC tot.	190	122/109	8	7180	15	310	570	21000	21100
av.	4	2	-	140	-	6	-	420	420

With 3 800 labor-years on the Moon and an average duty cycie of 6 months the capacity of the passenger flights must comprise 7 600 seats, or 7 600: 40 = 190 passenger rountrip missions. With the heavy delivery schedule of facilities plus the additional Earth propellants needed for the return flights in the early years, a fairly high launch rate results which might be difficult to achieve. Thus,the flight numbers indicated for year "0" might be distributed over two years, they are considered to be part of the development phase.

5. Inputs, outputs and performance of the lunar laboratory

The production oriented facilities on the Moon are considered to be at best pilot plants for various production experiments with one exception: the lunar oxygen production plant. This early oxygen plant has to produce enough propellants for the LUBUS flights. If it does not initially, the difference has to be imported from Earth by extra tanker flights. - The pilot production facilities deliver products of simple nature such as raw materials and feedstock, liquid oxygen and some more complex products such as construction materials processed in a mechanical workshop. Some are used on the surface of the Moon for additional infrastructure development such as roads, some could be available for export.

Facilities are extended by lunar produced elements and imported parts. The lunar produced components have to be substracted from the total mass for extention to obtain the imports required.
A summary of the lunar products with their annual mass flows including recycled masses, used as a reference for planning purposes is given in table 5-1.

Table 5-1: Projected outputs of early lunar facilities based on their theoretical mass growth rates (metric tons per annum)

year	lunar produced facility extensions	lunar produced spares	lunar produced consum-mables	total lunar products for direct lunar use	products for export or use TBD	lunar oxygen produced	total output of lunar facilities
1	0	3	44	47	12	125	184
2	8	5	51	64	13	190	267
3	5	6	55	66	22	200	288
4	7	7	62	76	26	290	393
5	4	8	65	77	31	310	418
10	5	11	82	98	40	370	508
15	6	15	101	122	46	400	568
20	7	18	121	146	49	425	620
30	7	24	150	181	56	450	687
4	5	29	170	204	64	480	748
50	3	32	180	215	75	500	790
LC total	235	1000	6450	7685	2600	21000	31285
an.av.	5	20	129	154	52	420	626

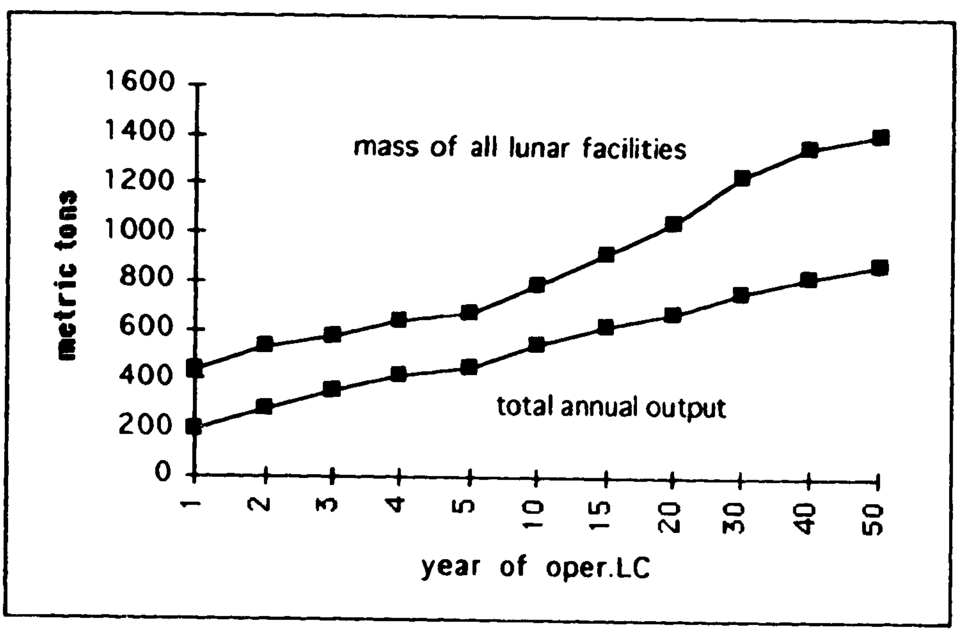

Figure 5/1: Comparison of lunar facility mass and annual output of all products

The consumables produced on the Moon include the gases (CO_2) and the biological wastes of the crew, but also the food produced in the biological laboratory (experimental farm) using part of the waste material.-
The spare parts listed in table 5-1 are either handmade parts in the workshop or reworked parts which have failed in the past.

The theoretical growth rates indicated in Tab. 5-1 are a consequence of the incremental growth of the facilities the model predicts. If these projections can be realized, this will lead in later years to an excess production that can be used for extending the lunar infrastructure, such as roads and power lines, much faster than planned and/or could also be exported. This excess capability listed in column 6 is 7.6% of the total production and may also be considered as a reserve.

The lunar production has to be supplemented by imports. The import rate per crew member will decline during the life cycle due to increased use of lunar products. All complex facilities and equipment will have to be imported, also most of the higher quality food. All mandatory consumables are summarized under the definition "other imports". It is premature to detail these partial masses at this time of the analysis. Since it is likely that there will be additional needs resulting from activities not yet foreseen. Some of the cargo might also be lost on the way to the Moon. Consequently there is a cargo import mass defined as "other imports". There remains a difference between the payload capability and the projected import mass listed in the last column.This may be used to import the required oxygen not provided by the current lunar production capacity.

Table 5-2 : Projected theoretical imports required by the operational lunar laboratory on the lunar surface as projected by the model (metric tons p.a.)

year	imported spare parts	imported facilities and equipment	other imports	total projected imports	nominal cargo capacity to LUS	additional LUS cargo available
1	16	0	45	46	70	24
2	21	89	46	146	140	-6
3	21	44	47	104	140	36
4	24	51	51	118	140	22
5	24	26	55	94	140	56
10	27	22	63	100	140	40
15	29	19	70	107	140	33
20	31	19	77	117	140	23
30	33	13	80	122	140	18
40	33	8	79	121	140	19
50	32	3	77	114	140	26
LC total	1500	750	3550	5800	6930	1130
av.	30	15	73	111	138	22

Taking the data from column 5 of table 5-1 and and column 5 of table 5-2 a comparison of the masses produced on the Moon for lunar purposes and the total projected imports is possible. After about ten years of operation more supplies come from lunar sources than from the Earth!

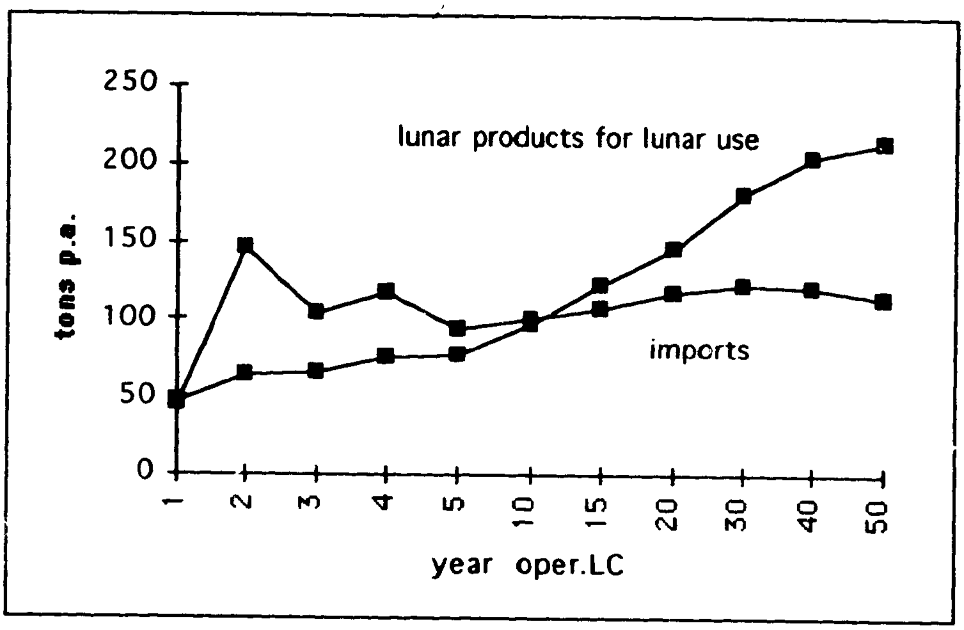

Figure 5/2 : Development trends of lunar products for lunar use and the mass of imports to the lunar surface

The above tables 5-1and 5-2 will eventually require some minor corrections due to the initial requirements during the acquisition period. These are calculated on a quarterly bases for the period lasting from the year preceeding the landing of the first crew up to and including the fifth operational year. This must be done to arrive at a realistic acquisition scenario and for the purpose of estimating cost to follow the next chapter.

6. The acquisition of the lunar laboratory

The development phase is part of the acquisition phase of the lunar laboratory. After reaching a decision to proceed with the program, which can be very time consuming as experienced with the international space station ALPHA, we know from previous programs that the development phase is the most critical one with respect to technical feasibility, operational feasibility and financial acceptability. -

Thus it is necessary to develop detailed plans for the total system particularly for the development period. This requires at this point a breakdown of the program activities and milestones on a quarterly basis from the time of program initiation up to the first flight test to develop a better understanding of the development sequence and time periods involved.

Table 6-1: Initial Program Development Schedule
year x = year of first development flights

year & Qarter	activity or flight mission
x-10	Program planning activities are initiated
x-9	program definition & specifications completed, memorandum of understanding (MOU) signed by partners
x-8	program approval, industrial competition for contracts
x-7/2nd Qtr	begin of vehicle and facility developments
x-7 /3rd Qtr	design begin of crew capsule for HLLV, crew cabin of LUBUS, and of lunar facilities; construction begin of launch facilities
x-6 /1st &2nd Qtr	design reviews of HLLV elements, the lunar power plant module and the lunar LOX production module
x-5/2nd Qtr	design reviews of crew cabin for LUBUS and the HLLV system
x-4 / 1st Qtr	design review of LUBUS stage, lunar habitat module
x-4/2nd Qtr	design review of lunar workshop module, lunar spaceport & mobility equipment
x-4/3rd Qtr	design review and approval of LUBUS system
x-4/4th Qtr	design review and approval of SOC modification
x-3/1st Qtr	design review of lunar base control system
x-3/2nd Qtr	begin of component testing of new elements
x-2/3rd Qtr	begin of prototype production of all vehicles and lunar facility modules
x-2/4th Qtr	begin of subsystem testing
x-1/1st Qtr	begin of assembly of prototype vehicles
x-1/2nd Qtr	begin of ground testing of prototype vehicles
x-1/3rd Qtr	completion of launch facilities
x-1/4th Qtr	acceptance test of prototype HLLV and LUBUS

A precise list of hardware requirements and a flight schedule must be available before cost estimates of the vehicles can be derived. This leads to a manifest for the flights planned with emphasis on the first five years.

Table 6-2: Detailed quarterly flightplan for the acquisition period
* = HLLV + LUBUS flights, all other HLLV flights without LUBUS
Year 0 used for initial flight tests, year 1 is the year of beneficial occupancy
Legend:
(1) Period of time (quarter)
(2) Flight tests of the HLLV prototype vehicle
(3) Flight tests of the HLLV + LUBUS prototype vehicles
(4) Direct flights of the 3-stage HLLV to LUS, 3rd stage one-way (45 t module)
(5) 2 stage HLLV flights to LEO in support of LUO-SOC acquisition (300 t LEO)
(6) HLLV Earth-Lox Tanker flights to LUO-SOC for replennishing (85 t)
(7) Delivery of partly fueled LUBUS units to LUO (20 + 50 t Lox)
(8) Special facility delivery flights with LUBUS roundtrip (70 t facility modules)
(9) Standard operational cargo flights (70 t equipment and supplies)
(10) Standard operational passenger flights (40 passengers + luggage)
(11) Total number of HLLV flights in this quarter
(12) Total number of LUBUS flights in this quarter

(1)	(2)	(3)*	(4)	(5)	(6)	(7)*	(8)*	(9)*	(10)*	(11)	(12)*
0/I	1									1	0
0/II	1	1								2	1
0/III		1		1						2	1
0/IV		1		1						2	1
1/I			2	1						3	0
1/II			1			1	1			3	2
1/III						1		1		2	2
1/IV					1				1	2	1
2/I						1	1	1		3	2
2/II						1			1	2	2
2/III							1	1		2	2
2/IV									1	1	1
3/-I-							1	1		2	2
3/II-					1				1	2	1
3/III							1	1		2	2
3/IV					1				1	2	1
4/I							1	1		2	2
4/II									1	1	1
4/III								1		1	1
4/IV									1	1	1
5/I								1		1	1
5/II									1	1	1
5/III								1		1	1
5/IV									1	1	1
SUM	(2)	(3)	3	3	3	4	6	9	9	42	30

Without the test flights during the last year of the development period ("0"), **35 HLLV and 27 LUBUS** vehicle flights are on the regular schedule for the first five operational years!

Mass balance check first five years

At the end of the fifth year the following masses must be on the Moon:

Lunar facilities and equipment as estimated by the model	668 t
imported spares	106 t
supplies	244 t
lunar produced facility mass	- 24 t
total mass required from the Earth	994 t

Total mass delivered from the Earth during first five years:

3 direct flights with complete modules 45 t each	135 t
6 regular cargo flights with facilities and equipment 70 t each	420 t
9 regular supply flights with cargo and equipment 70 t each	630 t
total delivered from the earth incl.reserves	1185 t

Lox propellant balance first 5 years

Lox left in SOC at arrival in LUO	200 t
Lox left in 4 LUBUS flights brought to the LUO-SOC	200 t
3 tanker flights of HLLV to LUO-SOC with 85 t each	255 t
total in LUO-SOC during first five years	655 t

LULOX produced by lunar facilities during first 5 years	1115 t

LOX requirements in LUO:

6 cargo flights with facilities from LUO to LUS, 50 t each	300 t
9 regular supply flights from LUO to LUS, 50 t each	450 t
9 regular passenger flights LUO to LUS, 25 t each	225 t
sub total	975 t

LOX requirements on LUS for ascent flights to LUO:

15 cargo vehicle flights empty, 34 t each	510 t
9 passenger return flights 25 t each	225 t
sub total	735 t

Grand total of Lox required in LUO and on LUS	1710 t

Balance: Available 1115 + 655 = 1770 t - required 1710 t = 60 t reserve

This reserve will probably be needed to cover vaporization losses ! This balance shows that the planned flight schedule for the logistic support of a laboratory with the desired attributes and performance is adequate.

We are now in the position to specify the missions and payloads for each of the flights scheduled during the flight operations in the early years of the acquisition. At this point in time it is sufficient to use a quarterly schedule which has to be replaced later with a monthly schedule to make sure that the needs of the initial lunar crew are satisfied.

Table 6-3: Manifest for HLLV and LUBUS flights

quarter	vehicles	missions
0/I	HLLV	1st test flight with 2 stages to LEO for recovery
0/II	HLLV HLLV+Lubus	test flight with 3 stages to LUO and return test flight to LEO for Lubus flight test + rendevouz
0/III	HLLV+Lubus HLLV	back-up vehicle for systems test 2stage flight with SOC module to LEO
0/IV	HLLV+Lubus HLLV	systems verification flight test to LUO + return 2stage flight to LEO with propellants for SOC
1/I	HLLV HLLV HLLV	3stage dir. flight to LUS with 45 t fac. module 2stage flight to LEO with propellants for SOC 3stage dir.flight to LUS with 45 t facility module
1/II	HLLV+Lubus HLLV HLLV+Lubus	3stage flight to LUO/LUS with 70tfac. module 3stage dir.flight to LUS with 45 t fac.module 3stage transfer 3stage transfer flight of Lubus to LUO +50 tlox
1/III	HLLV+Lubus HLLV+Lubus	3stage transfer flight of Lubus to LUO +50 t lox 3stage flight to LUO/LUS with 70 tsupplies
1/IV	HLLV HLLV+Lubus	3stage tanker flight to LUO with 85 t lox 3stage passenger flight to LUO/LUS & return
2/I	HLLV+Lubus HLLV+Lubus HLLV+Lubus	3stage flight to LUO/LUS with 70 t facility module 3stage flight to LUO/LUS with 70 t supplies 3stage transfer flight of Lubus to LUO +50 tlox
2/II	HLLV HLLV+Lubus HLLV+Lubus	3stage dir.flight to LUS with 45 t fac.module 3stage passenger flight to LUO/LUS & return 3stage transfer flight of Lubus to LUO +50 tlox
2/III	HLLV+Lubus HLLV+Lubus	3stage flight to LUO/LUS with 70 t facility module 3stage flight to LUO/LUS with 70 t supplies
2/IV	HLLV+Lubus	3stage passenger flight to LUO/LUS & return
3/I	HLLV+Lubus HLLV+Lubus	3stage flight to LUO/LUS with 70 t facility module 3stage flight to LUO/LUS with 70 tsupplies
3/II	HLLV HLLV+Lubus	3stage tanker flight to LUO with 85 t lox 3stage passenger flight to LUO/LUS & return
3/III	HLLV+Lubus HLLV+Lubus	3stage flight to LUO/LUS with 70 t facility module 3stage flight to LUO/LUS with 70 t supplies
3/IV	HLLV HLLV+Lubus	3stage tanker flight to LUO with 85 tlox 3stage passenger flight to LUO/LUS & return
4/I	HLLV+Lubus HLLV+Lubus	3stage flight to LUO/LUS with 70 t facility module 3stage flight to LUO/LUS with 70 t supplies
4/II	HLLV+Lubus	3stage passenger flight to LUO/LUS & return
4/III	HLLV+Lubus	3stage flight to LUO/LUS with 70t supplies
4/IV	HLLV+Lubus	3stage passenger flight to LUO/LUS & return
5/I	HLLV+Lubus	3stage flight to LUO/LUS with 70t supplies
5/II	HLLV+Lubus	3stage passenger flight to LUO/LUS & return
5/III	HLLV+Lubus	3stage flight to LUO/LUS with 70t supplies
5/IV	HLLV+Lubus	3stage passenger flight to LUO/LUS & return

7. Program Cost

7.1 Non-recurring cost

The program structure is the basis for estimating program cost, it was developed and presented in the previous chapter. To estimate cost and distribute these over the calender years is the next task to be accomplished.

This cost estimate begins with the non-recurring costs of the program to be carried out during a nine year development and test phase, before the operational phase can be initiated. These costs are primarily the development costs and first unit costs derived by cost estimating relationships developed during the last decades. In case pre-production of vehicles or modules are required due to the anticipated schedules, these are estimated at the level of first unit costs.

This is followed by an estimate of the recurrent cost of the lunar base facilities and the logistic system during its operational phase. Knowing the masses and numbers of facilities and vehicle flights required, it is possible to derive at preliminary cost estimates for the various elements of the Lunar Laboratory. This estimate was done with the help of cost models (LUBSIM and TRASIM), based on codes developed during the last 25 years at the TU Berlin[2,10].

The following comments will help to understand the calculation procedure used for deriving the non-recurrent costs listed in the specified columns of table 7-1 :
Legend:
(1) Development cost the the heavy lift launch vehicle (HLLV) and lunar lander (LUBUS), including prototype, ground facilities and flight testing, but excluding crew cabins and payload containers.
(2) Cost of development of crew modules and payload containers for HLLV and LUBUS including prototypes and flight tests.
(3) One pre-production unit - in addition to the prototypes - of all elements of the space transportation system (other than the SOC) as back-up in case of mishaps. - This is not included in the original model and has to be accounted for separately!
(4) Development cost of the space operation center (LUO-SOC) on the bases of a modification of the second stage of the HLLV. The production of the first complete unit will be listed not under development but under production cost.
(5) Total cost of the logistic system R&D phase, items (1) thru (4)
(6) Initial development cost of lunar facilities prior to initial beneficial occupancy.
(7) Cost of first units of lunar facilities and equipment,if manufactured during the years before the beginning of the operational period (year no.1). Included are also three 3rd stages of the HLLV which -after landing - will remain on the Moon serving as storage containers at 250 m $ each, not included in the model!
(8) Cost of planning activities including training of initial lunar crew members, this is not included in the original model!
(9) Total lunar base facilities =(6) + (7) + (8)
(10) Total lunar laboratory project = (5) + (9)

Table 7-1: Non-recurrent cost of lunar laboratory (million 1990 dollars)

year	(1)	(2)	(3)	(4)	(5)
-8	40				40
-7	1780	23		45	1848
-6	2730	910		62	3702
-5	3480	1280		78	4838
-4	3980	1650		88	5718
-3	4020	1810		88	5918
-2	3590	1670	704	78	6042
-1	2860	1350	1000	62	5272
0	2080	950	1200	45	4275
totals	24 560	9 643	2 904	546	37 653

year	(6)	(7)	(8)	(9)	(10)
-8			10	10	**50**
-7	240		50	290	**2138**
-6	600		50	650	**4352**
-5	960		50	1010	**5848**
-4	1200		50	1250	**6968**
-3	1800		50	1850	**7768**
-2	1800	460	50	2310	**8352**
-1	1200	460	120	1780	**7052**
0	600	460	220	1280	**5555**
totals	8 400	1 380	650	10 430	**48 185**

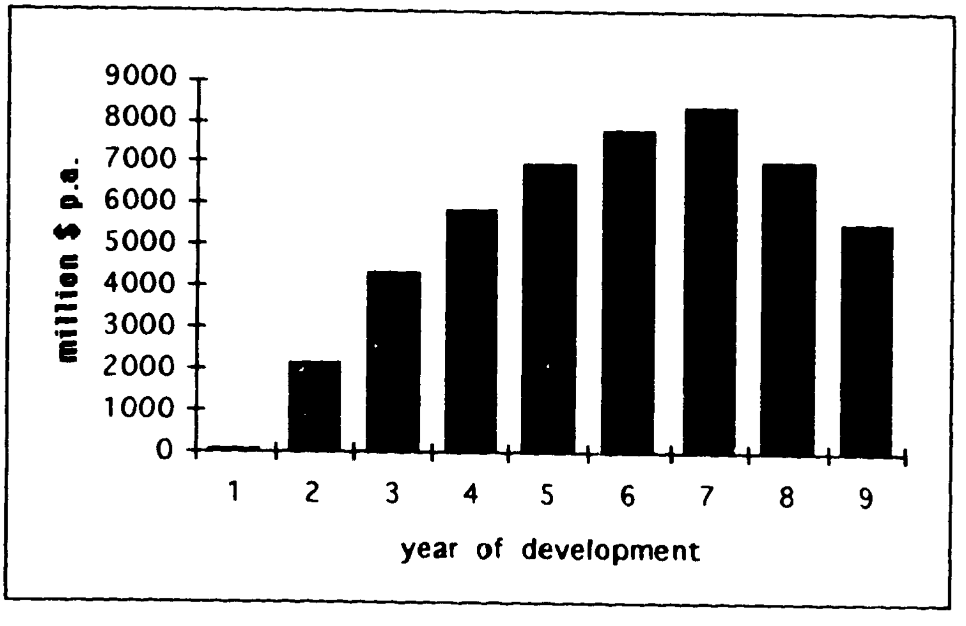

Figure 7/1 : Distribution of expenditures for development and testing of the elements comprising the lunar laboratory project (space transportation system and lunar facilities)

7.2 Recurrent cost of laboratory

The "recurrent cost" during the operational phase are presented next, first of the lunar facilities and equipment to be followed by the recurrent cost of the space transportation system.

Table 7-2 presents the direct operating costs associated with the lunar facilities proper. This includes the imports such as equipment and consumables. It indicates the estimated level of supporting effort required back on Earth in the areas of sustained engineering for facility extensions and improvements, but also administration, training of lunar crews and their salaries. All this adds up to the operating cost of the LULAB facilities, but does not include transportation cost. Alternatively the LULOX cost are deducted because they have been charged to the space transportation system.

The following explanations on the columns of table 7-2 may be helpful to understand the estimating procedure for the recurrent laboratory costs:
Legend:
(1) Operational year.
(2) Cost of sustained engineering,training of lunar crews and administration supporting activities on the lunar surface (the largest share of all cost elements!)
(3) Salaries of the lunar crew members including their duty cycles on Earth.
(4) Cost of facility modules, equipment and other imports.
(5) Cost of Earth ground support of science operations on the Moon.
(6) Cost of reimbursed Lulox from LSTS at a rate of 0,6 m $/t
(7) Total cost of LULAB activities on the Moon during the operational years without and with consideration of reimbursed lulox cost.

Table 7-2: Direct operating cost of lunar laboratory (million 1993/94 $ p.a.)

(1) year	(2) sust.eng admin. crew training	(3) lunar crew salaries	(4) total import goods	(5) science support	(6) re-imbursed Lox cost	(7) total LULAB recurrent cost/ minus lulox cost
1	408	20	26	100	0	554/554
2	408	25	220	100	0	754/754
3	408	27	153	100	246	688/442
4	408	30	158	100	210	696/486
5	408	31	109	100	174	648/474
10	408	39	107	100	225	654/429
15	408	47	112	100	225	667/442
20	408	56	120	100	276	684/408
30	408	67	124	100	327	699/372
40	408	74	128	100	327	710/383
50	408	75	132	100	327	715/388
LC total	20 400	2 860	5 965	5 000	13 356	**34 225/20 869**
average	408	57	119	100	267	**684/417**

7.3 Recurrent cost of the space transportation system

The LSTS is comprised of the two vehicles HLLV and LUBUS plus the LUO-SOC their costs are somewhat more difficult to determine. A total of 325 HLLV roundtrip flights and 306 LUBUS missions take place in this program. These vehicle costs are estimated with the TRASIM model of the Aerospace Institute of the TUBerlin (1990)[10]. They are presented in tables 7-3 and 7-4.

Legend :

(1) Operational year of the life-cycle

(2) Cost of sustained engineering and product improvement during the operation of HLLV and LUBUS.

(3) Production cost for both vehicles and LUO-SOC with full cost of a unit listed in the year of delivery (producing the irregular distribution observed in the table), excluding one HLLV which was already considered as a preproduction unit under development costs, but including the production cost of the LUO-SOC.

(4) Operational cost for the individual vehicle flights, including LUO-SOC operations , flight control, spares, replacements, refurbishment, maintenance, launch preparation etc.

(5) Sum of columns (2)+(3)+(4).

Table 7-3 is continued in table 7-4 with the following parameters:

(6) Direct cost per HLLV flight with passengers from Earth to LUO and back with depreciation of production costs over all flights, but excluding front-end costs.

(7) Direct cost per LUBUS flight with passengers from LUO to LUS and back LUO with depreciation of production costs over all flights, excluding front-end costs.

(8) Direct cost per passenger roundtrip mission Earth spaceport to lunar spaceport.

(9) Direct cost per cargo trip one way Earth spaceport to lunar spaceport and empty return.

(10) Dividing the cost per passenger flight (HLLV + LUBUS) by the number of seats available, one obtains the recurrent roundtrip cost per seat in that particular year. Unoccupied seats are increasing the cost proportionally.

(11) Dividing the cost per cargo flight (HLLV + LUBUS) by the nominal cargo payload one obtains the recurrent cost per kg cargo transported to the lunar surface via the LUO-SOC. These LUO-SOC services are included in the cost given.

Table 7-3: Overview of sustained engineering, production, operations and total cost during the operational phase (million 19903/94 $)

(1) year	(2) sustained engng. cost	(3) production cost	(4) operations cost	(5) total cost
1	283	5887	1294	7465
2	283	2512	862	3657
3	283	114	801	1197
4	283	2340	551	3175
5	283	161	442	859
10	283	55	521	969
15	283	50	510	842
20	283	66	592	940
30	283	2015	658	2956
40	283	57	645	984
50	283	54	636	974
TOTAL	14 155	32 490	30 465	77 110
annual av.	283	650	609	1 542
percent	18,4	42,1	39,5	100

Table 7-4: Overview of space vehicle direct operations cost of primary flights and specific transportation costs of cargo and passenger transportation during the operational phase (million 1993/94 $)

(1) year	(6) dir.cost p.pass. flight HLLV	(7) dir.cost p.pass. flight Lubus	(8) tot.dir. cost pass.fl. ES-LUS	(9) tot. dir. cost cargo fl. ES-LUS	(10) cost per passen-ger seat ES-LUS	(11) $/kg cargo direct ES-LUS
1	160	238	398	270	9,94	3467
2	149	49	198	200	4,94	2462
3	145	50	195	198	4,87	2480
4	159	53	211	216	5,29	2688
5	159	54	212	217	5,31	2711
10	152	52	204	209	5,10	2607
15	148	52	200	205	5,00	2560
20	137	50	187	192	4,66	2404
30	126	46	172	177	4,29	2208
40	122	46	168	174	4,20	2179
50	121	45	166	172	4,16	2163
ann.av.	132	49	180	195	4,52	2437

The mission costs of passenger and cargo missions shown in columns (4) and (5) are plotted vs time in figure 7/2.

The specific transportation cost trends of the columns (10) and (11) are presented in figure 7/3. They are calculated based on the assumption that the vehicles will fly as often as their design life will allow. In this scenario, however, this is not the case. The number of vehicles is determined by the minimum number of vehicles required on the flight-line. When they are taken-off, they will have a residual value because the production costs are prorated over the number of flights designed into the vehicles. Thus, the specific costs given below are considered to be the lower limit, they could be about 10 % higher. In case the nominal payload capacity of the vehicles is not fully used, the cost go up proportionally.

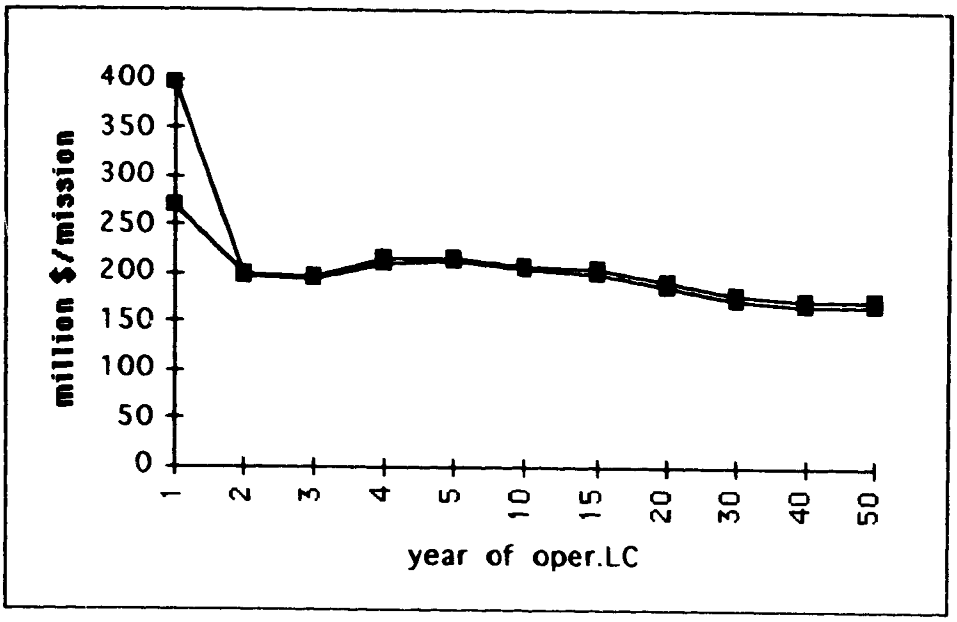

Figure 7/2: Mission cost for passengers (upper curve - million 1993/94 $ and for cargo (lower curve - million 1993/94 $)

The production cost of the individual vehicle is paid fully in the year of delivery in this model. Any financing costs will have to be part of this cost. Consequently the annual expenditures is very irregular as can be seen in column 5 of table 7-3. This is listing for selected years the annual expenditures required for the lunar logistic system employed in this model. In reality the peaks will be lower since it is common practice to pay one third of the cost when the vehicle is ordered, one third in the second year and the last third upon delivery.

In addition to the total operational expenditures, the total costs per round trip including the residual values of the vehicles at the end of the life-cycle as well as the prorated up-front cost of a passenger flight and a cargo flight is given in table 7-5 and figure 7/3 to obtain a more complete picture.

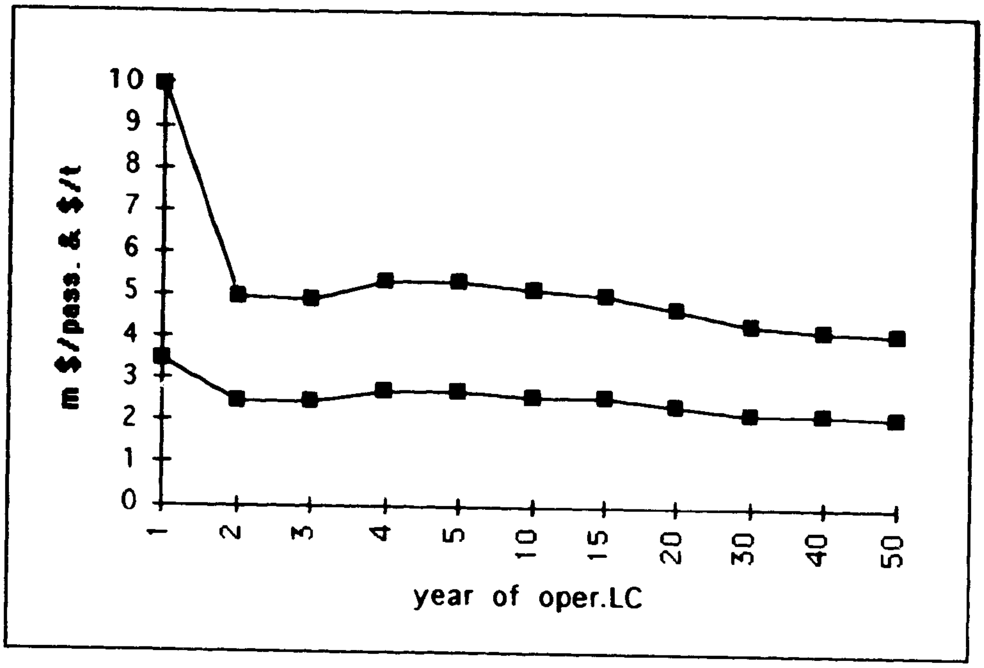

Figure 7/3: Specific recurrent transportation cost for passengers (upper curve - million 1990 $/seat) and for cargo (lower curve - million 1990 $/metric ton delivered to the Moon)

Table 7-5 : Overvi°**w of total transportation system cost with prorating production cost and up-front cost equally over the operational years operations and total cost during the operational phase (million 19903/94 $)**

(1) year	(2) up-front incl. sust.engng. cost	(3) production cost	(4) opera-tions cost	(5) total cost
1	1036	650	1295	2938
2	1036	650	862	2550
3	1036	650	801	2489
4	1036	650	551	2239
5	1036	650	442	2130
10	1036	650	521	2209
15	1036	650	510	2198
20	1036	650	592	2280
30	1036	650	658	2346
40	1036	650	645	2333
50	1036	650	636	2324
TOTAL	51808	32490	30465	114763
ann.av.	1036	650	609	2295
percent	18,4	42,1	39,5	100

In calculating the cost per roundtrip, the production cost are prorated over the number of maximum flights the vehicle is designed for if fully used during its lifetime. This scenario will not fully use the number of allowed flights, thus they will have a residual value when taken off the flight line.

8. Specific costs of lunar products and services

As a consequence of these investments and activities the lunar laboratory is producing values by offering services, such as laboratory spaces, or products, such as construction material and feedstock. The mass flows and services per se have been presented in table 5-1 in absolute terms, but not their specific costs.If the costs of the lunar base operation are prorated on the bases of mass flows, human labor and energy consumed over all products and services offered including the overhead, then we obtain the specific cost of products and services. If we can find a market for some of these, we would be able to reduce the expenditures to be provided by public funds in the beginning of this extraterrestrial human activity accordingly. The following table presents first the data assuming that the transportation costs are *not* prorated over the individual products and services. In a commercial environment the transportation cost would have to be included and then would lead to theoretical minimum costs only, since they do not yet take into consideration interest, taxes and profits. Thus commercial prices would be higher than shown in the next tables.

Table 8-1: Specific direct costs of lunar products and services excluding their share of logistic costs,financing and profit.

YEAR	LULOX ($/kg)	Lulab (m$/ MY)	Work-shop (m$/ MY)	Habitat (m$/ MY)	Control Center (m$/ MY)	Power ($/ MWh)	Self-Support goods ($/kg)	Export goods average ($/kg)	av.total lunar out-put ($/kg)
1	2476	42,1	19,2	11,2	47	12420	7372	5392	2735
2	2686	45,5	41,7	11,4	47	17140	6744	5042	2831
3	1494	24,3	14,3	6,7	36	9026	4243	3009	1618
4	1220	20,1	14,8	6,4	34	7787	3547	2433	1320
5	953	16,6	12,8	5,4	32	4302	3159	1954	1044
10	734	11,7	12,5	4,8	28	3604	2497	1435	802
15	634	9,6	10,9	4,1	24	3807	1956	1241	695
20	580	8,4	9,8	3,7	21	3175	1760	1124	635
30	517	7,1	8,6	3,3	18	2595	1458	1019	571
40	492	6,4	8,0	3,1	17	2261	1303	988	546
50	484	6,2	7,7	3,0	17	2058	1212	986	548
aver.	608	7,7	10,8	3,6	21	2979	1690	1174	674

Of particular interest of the items on this table are the specific cost of lunar produced oxygen listed in the first column. The life-cycle average price is 608 $/kg which is an equivalent of 3.0 labor-years. This value is to be entered into the

TRASIM model as the price to be paid for using lunar LOX to obtain the total transportation cost.

Also of special interest is the next column, indicating that a working space in the laboratory research and development facilities could be leased for a *average* of 3,8 million $ per 6 month activity period, but not including the roundtrips of the research scientist which are on the average 4,5 million $. This total of about 8 to 9 million $ appears reasonable if compared to the cost of space-station trips which have been sold for 20 million $ in the past.

In general, to produce lunar products within the frame of a lunar laboratory is fairly expensive because the production volume of this science oriented operation is low. The individual products have to be analysed on their own merrits, however,the trends are presented in table 8-1 and on figure 8/1.

It was found that lunar oxygen is cheaper than imported oxygen from Earth. If hardware products (spares and construction material) and lunar produced food are considered ("lunar products for lunar use"), then we have to wait about ten years to arrive at the break-even point. On the other hand the average cost - including raw materials and lunar oxygen - is in a range clearly below the specific transportation cost. If a fair comparison is to be made, the production costs of the products manufactured on Earth have to be added to the specific transportation cost. Also the pleasures from growing part their own vegetables will enhance the well being of the lunar crew. A more detailed analysis is thus recommended for a specific scenario and life-cycle.

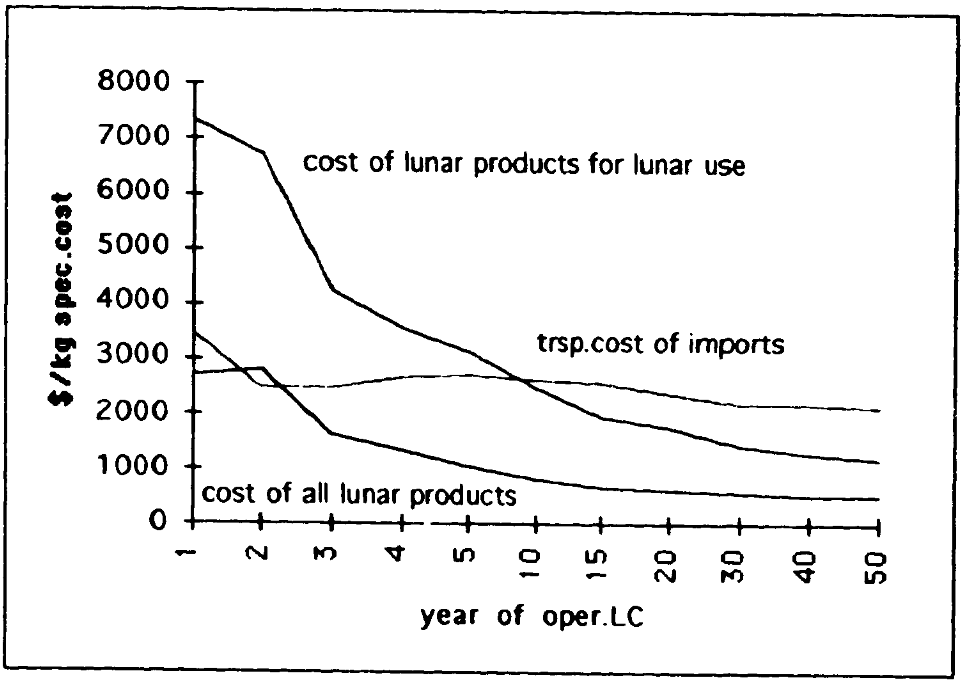

Figure 8/1: Comparison of specific cost of lunar products with the specific transportation costs of Earth-lunar cargo delivery

The other limiting case is an operation where the lunar laboratory operation will be charged with the non-recurrent and recurrent cost of the lunar space transportation system. In this case the total space transportation cost are a burden to be distributed over all lunar products and services thus increasing their specific costs. Not yet included are those charges connected with a fully commercial operation such as financing cost and profit,however.

Table 8-2: Theoretical specific direct costs of lunar products and services including their logistic burden, but not the cost of financing and profit.

YEAR	LULOX ($/kg)	Lulab (m$/MY)	Work-shop (m$/MY)	Habitat (m$/MY)	Control Center (m$/MY)	Power ($/MWh)	Self-Support goods ($/kg)	Export goods average ($/kg)	av.total lunar out-put ($/kg)
1	5485	88	58	28	47	25342	15673	12028	6075
2	6598	120	130	30	47	38548	16774	12816	6985
3	3712	71	49	18	36	19845	11000	7796	4050
4	3194	64	54	19	34	17922	9942	6706	3486
5	2344	53	45	15	32	12128	8629	5092	2599
10	1843	43	44	14	28	9738	7439	3880	2044
15	1662	39	42	13	24	8596	6436	3569	1858
20	1538	36	39	12	21	7764	5736	3313	1724
30	1410	32	36	11	18	6680	4964	3043	1610
40	1110	23	26	8	17	4851	3547	2564	1284
50	920	18	20	7	17	3857	2752	2180	1087
aver.	1482	29	38	10	21	6756	4942	3174	1683

This answers more precisely the question if and when oxygen is to be imported to the lunar laboratory or produced there in this scenario:

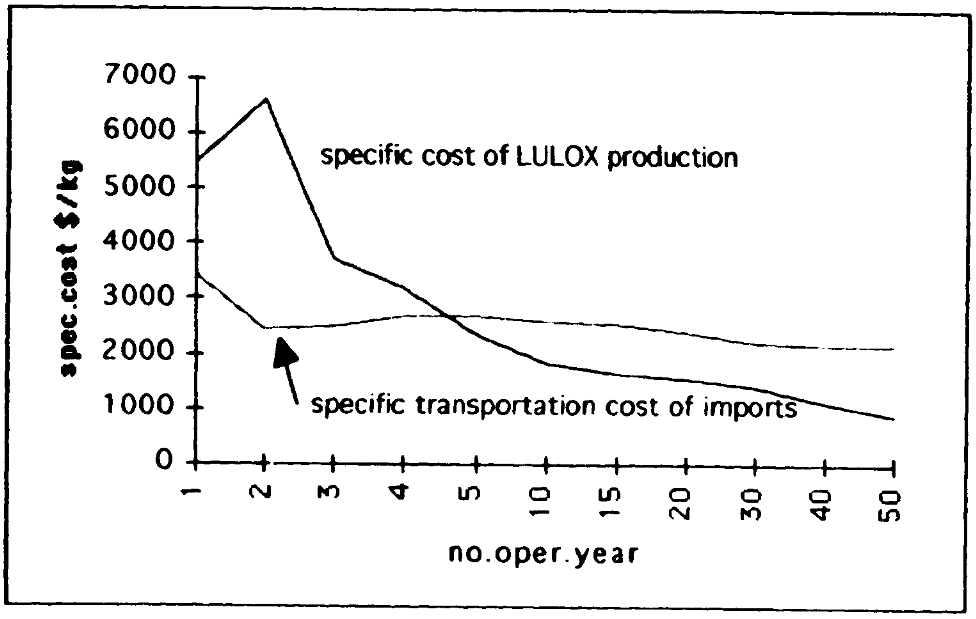

Figure 8/2: Trend of specific cost of transportation of imports and production of lunar oxygen.

This diagram shows that in a laboratory type of a lunar base - not optimized for production - but taking into consideration the cost of space transportation, it is more cost effective during the first years to import liquid oxygen than to produce on the Moon.But after about five years it is the other way around. It should also be noted that under these assumptions the Lulox cost are higher than those assumed to be paid by the transportation system operator (1.48 vs 0.6 m $/t), the difference must considered to be a grant by the operating institution or systems operator respectively. Alternatively one has to repeat the calculation with the corrected Lulox cost in an iterative manner. One has to watch out,however, that the lulox cost are not taken into account twice.

Multiplying the specific cost of lunar products and services with the annual amounts (mass, labor years, kWh) yields the annual "sales" to be realized in terms of million (1990) $, if they are to cover the cost of the operation.
The lunar laboratory would have - under these assumtions - the following sales potential:

Table 8-3: Projected total annual sales potential (million $ p.a.) if the total transportation cost are charged to the lunar operator

YEAR	exports or infra-structure	pro-pellants	port services overhaul vehicles	labora-tory spaces	sales of all prod. and services	products used by lunar base
1	142	685	100	174	1101	66
2	162	1261	360	537	2320	247
3	171	901	95	490	1657	140
4	176	922	100	603	1802	162
5	160	728	83	632	1601	125
10	155	679	79	844	1758	151
15	162	668	79	1056	1964	164
20	161	654	79	1239	2132	178
30	179	645	80	1440	2343	188
40	164	532	68	1138	1902	164
50	162	459	61	880	1562	116
MEAN	166	628	81	1036	1911	152

9. Cost Summary and System Effectiveness

A typical lunar laboratory has been structured and analysed with respect to mass flows, energy and human labor requirements in sufficient detail to derive at fairly realistic cost estimates for the up-front and operational costs. These have to be combined with the attributes and performance of the entire lunar laboratory system including the logistics of it during the entire life cycle,which was assumed to be 10 years for development and 50 years of operation.

Cost summary

To obtain the total cost of the program one has to estimate the two major elements of the system, the *space transportation system* and the *lunar base* separately first. If the space transportation operator reimburses the lunar base operator for the Lulox used at an agreed price level, then the total amount paid to the lunar base operator for the Lulox used during the life-cycle have to be deducted from the total base cost! This is the basis for the cost summary to follow.

Table 9-1 : Lunar Laboratory life-cycle cost summary (million 1993/94 $) with 10 + 50 year life-cycle

COST ELEMENT	Life cycle m $	Life cycle m $ p.a.	% of total
Development & test lunar facilities-10y	10 430	1043	7,1
Dev.& test of space transp.system-10y	37 653	3765	25,9
Subtotal Development & Test - 10 y	**48 185**	**4818**	**33,0**
sustained engineering LSTS- 50 y	14 155	283	9,7
Production space transportation system	32 490	650	22,2
Operation space transportation system	30 465	609	20,8
Operation lunar facilities	20 870	418	14,3
Subtotal operations - 50 years LC	**97 980**	**1960**	**67,0**
Total Lunar Laboratory System - 60 y	**146 165**	**2436**	**100**

An illustrative cost trend over the operational life-cycle can be obtained, if the development costs and the production costs are amortized over the fifty year operational life-cycle with equal amounts p.a. This has been done numerically in table 9-2 and graphically in figure 9-1

Table 9-2 : Lunar laboratory system operational life-cycle cost trends (million 1993/94 $) with up-front cost prorated over operational life-cycle

oper. year	dev. & test lunar facilities	dev. & test LSTS+ product improv.	produc-tion LSTS	operation LSTS	operation lunar facilities	total p.a.
1	209	1036	650	1295	554	3744
2	209	1036	650	862	754	3413
3	209	1036	650	801	442	3140
4	209	1036	650	551	485	2933
5	209	1036	650	442	474	2813
10	209	1036	650	521	428	2846
15	209	1036	650	510	442	2849
20	209	1036	650	592	408	2897
30	209	1036	650	658	373	2928
40	209	1036	650	645	383	2925
50	209	1036	650	636	388	2921
sum LC	10 430	51 808	32490	30465	20870	146063
av.p.a.	209	1036	650	609	417	2921

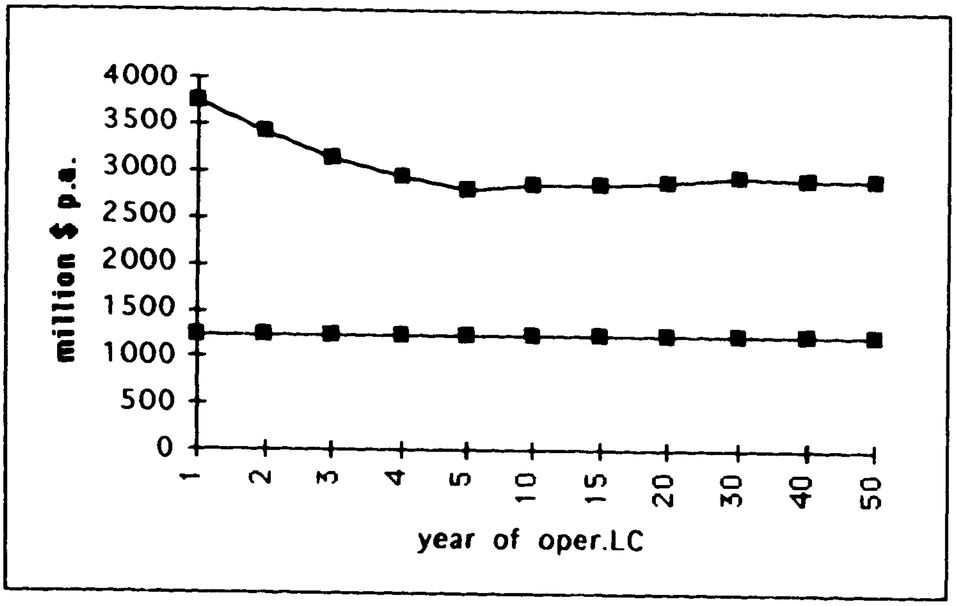

Figure 9/1: Lunar Laboratory Sytem total cost trend (upper curve) with development cost (lower curve) and production costs amortized over the fifty year operational life cycle

Program effectiveness

Program objectives, program structure and program cost are the elements required to determine program effectiveness.This effectiveness is the most important criteria for a go/no-go decision.

The factors depicting the annual trend give a more complete insight into the behaviour of the system analysed than cumulative values. The primary parameters selected for this overview presented in Tab. 9-3 are the following:

(1) Systems life-cycle cost per lunar labor-year (million 1993/94 $/labor-year)
(2) Systems life-cycle cost per lunar science year (m 1993/94 $/ laboratory place)
(3) Systems life-cycle cost per unit mass produced on the Moon (m 1993/94 $ t)
(4) Lunar facility mass per lunar crew member (t/ person)
(5) Imports per lunar crew member (t p.a./ person)
(6) Lunar manufactured products per lunar crew member (t p.a./person)
(7) Share of import mass per unit mass of lunar products (%)
(8) Mass of lunar products per unit mass of lunar facilities (t p.a./t)
(9) Installed power per unit mass of lunar products (kW/ t p.a.)

Table 9-3: Development trends of primary system-effectivness ratios

year	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	139	1872	20,3	16,1	2,6	6,8	38	0,42	5,39
2	103	853	12,8	16,1	4,2	8,1	52	0,50	5,37
3	90	449	10,9	16,6	4,0	8,2	49	0,50	6,01
4	73	326	7,46	16,0	3,5	9,8	36	0,62	5,18
5	67	234	6,73	15,9	3,3	10,0	33	0,63	5,23
10	55	142	5,60	15,3	2,7	10,0	28	0,64	5,48
15	45	107	5,02	14,6	2,2	9,0	25	0,62	5,85
20	39	84	4,67	14,1	1,9	8,4	23	0,59	6,23
30	33	65	4,26	13,7	1,6	7,6	20	0,56	6,98
40	30	59	3,91	13,8	1,4	7,6	19	0,55	7,45
50	29	59	3,70	14,1	1,4	7,9	18	0,56	7,74
av.	38	82	4,67	14,5	1,8	8,2	22	0,60	6,70

The following table describes the life-cycle performance of the lunar laboratory program by listing the most important state-variables and parameters. These data are suitable to compare options for lunar development. While this summary is neither a complete picture nor a very accurate data base, it is the best presently available and awaits further improvements.

Table 9-4: Life-cycle performance and cost summary of a lunar laboratory program
- (cost in million 1993/94 dollars ; 1 labor year = 200 000 $)

lunar facilities available at the end of the life-cycle	1 408 t
total lunar products available	31 285 t
--- LC lunar propellants used for space vehicles	21 200 t
--- LC lunar products for infrastructure extension or export	2 600 t
--- LC lunar products used directly by the lunar laboratory	7 685 t
total lunar labor-years available	3 800years
--- laboratory years available for lease	1 785 years
cost of planning and program integration activities	650 m $
initial development cost of lunar facilities	8 400 m $
production cost of initial facilities	1 380 m $
lunar facilities acquisition	10 430 m $
cost of engineering support during expansion of lunar facilities, administration and training	20 400 m $
salaries of lunar crew	2 860 m $
cost of imported spares, equipment & consumables	5 965 m $
cost of lunar science support (100 million $ p.a.)	5 000 m $
reimbursed lunar produced oxygen	- 13 356 m $
operations cost of lunar facilities	20 869 m $
subtotal lunar laboratory acquisition and operation	**31 299 m $**
cost of space vehicle development and engineering	34 749 m $
pre-production of backup vehicles	2 904 m $
total space transportation system development cost	37 653m $
product improvement during operation	14 155 m $
total production cost	32 490 m $
total operations cost	30 465 m $
total recurring cost lunar space transportation system	77 110 m $
subtotal logistic system	**114 763 m $**
total LULAB system cost for 60 yr life-cycle	**146 062 m $**
annual average during the 9 dev.+ 50 oper. = 60 year life-cycle	2 434 m $
cost per lunar labor-year	**38,4 m $/y**
cost reduction factor compared with OPTION I (15 year Temporary Lunar Outpost) 453 m $: 38,4	11,8 or 8,4 %

10. Summary and Conclusions

In the process of analysing and evaluating alternative plans for the next phase of lunar development four different near-term plus three far term options have been investigated by means of detailed simulation models. These have allowed a year to year estimate of the most important system parameters and the system behavior as a whole. The near-term options analysed are:

1. A temporary *Lunar Outpost* with a crew of up to 12 people, a 10 year development period and a 15 year operational life-cycle.
2. A permanent Lunar Outpost with a crew of up to 12 people, a 10 year development period and a 50 year operational life-cycle.
3. An extended *Lunar Outpost* with a crew of up to 24 people, a 10 year development period and a 50 year operational life-cycle.
4. A *Lunar Laboratory* with a crew of up to 100 people, a 10 year development period and a 50 year operational life-cycle.

These four alternatives are considered the primary applicants for a new phase of lunar development early in the 21st century. Additional options, such as a *Permanent Lunar Base*, a *Lunar Industrial Complex* and a *Lunar Settlement* have been analysed[17], but these are considered to be options for a third phase of lunar development in the middle of next century. For this reason they are not made part of this comparison.

The first three options are supported by a single stage space vehicle system complemented by a space operations center in low Earth orbit(LEO-SOC), serving as a transportation node. Two different versions of the single stage space vehicle are employed in this logistic system. An *SSTO Shuttle* to transport propellants, payloads and people to low Earth orbit, where an other single stage *Space Ferry* would take over for the trip to the Moon. Both vehicles are reusable, but their payload capabilities are limited by the size of the SSTO selected to be 800 metric tons. This results in a payload capability of about 20 t per flight.

A heavy lift transportation system(HLLV) of the *NEPTUNE* type[10] is used for the 4th option: A 3stage vehicle carries the mixed payloads directly to lunar orbit, where a space operations center is employed as a transportation node(LUO-SOC), enabling maximum use of lunar oxygen for refueling. The payload capability can be as large as 40 people or up to 100 t to lunar orbit. A lunar landing and launch vehicle - *LUBUS* - takes care of the leg between lunar orbit and the lunar base.

Table 10-1 compares the economic performance of these four alternatives. It is surprising to note,that the average annual expenditures of all options are below 3 billion (1993/94) dollars and not much different. The cost-effectiveness, however, (shown in the last two columns) of the lunar outpost is - as expected - improving with the length of life-cycle and with the number of lunar crew members. A dramatic improvement of the system-effectiveness is achieved by the *Lunar Laboratory* due to its larger crew and more cost-effective transportation system.

Table 10-1: Comparison of the economic performance of the Lunar Laboratory with alternative Lunar Outpost Options (1993/94 $)

Lunar outpost type	max crew size	labor years	science years	up-front cost	LC cost b$	av.cost p.a. b$	m$/ labor-year	m$/ science year
15 year temporary Lunar Outpost	12	140	50	29.7	64	2.56	453	1268
50 year extended Lunar Outpost	12	570	250	38.7	139	2.32	244	556
Enlarged 50 year Lunar Outpost	24	956	478	56.7	159	2.65	166	322
Lunar Laboratory 50 yr life-cycle	**100**	**3800**	**1785**	**48.2**	**146**	**2.43**	**38,4**	**81,8**
improvement ratio vs the 50 yr -24 person outpost	**420%**	**400%**	**370%**	**85%**	**92%**	**92%**	**23%**	**25%**

There is an other factor which is of great importance. It is the potential sales connected with the laboratory spaces available. It is quite likely that some of this potential can and will be used commercially by interested institutions and international corporations. Depending on the yield obtainable from the lease and from the degree this commercial potential is used, the annual cost to the public can be reduced accordingly. This is illustrated in figure 10/2.

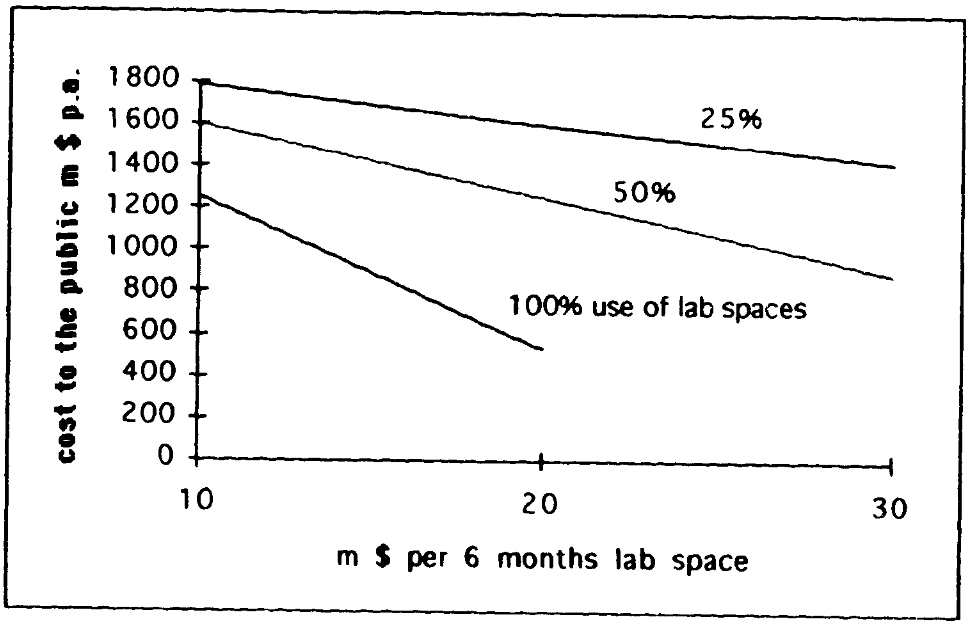

Figure 10/1: Reduction of average annual public funds for the operation of the lunar laboratory as a function of utilization of the available laboratory spaces by commercial customers and of the yield per lab space in terms of million (1993/94) $ for a 6 month period on the Moon including transportation of one person

CONCLUSIONS:

1. There is no quick,dirty and cheap solution to return to the Moon soon and proceed with a meaningful activity of lunar exploration within the defined objectives of the lunar development program.

2. Based on present or near term state-of-the-art it is possible to develop concepts of returning to the Moon to establish semi-permanent or permanent lunar facilities and to continue the lunar exploration early in the next century at affordable expenditures and an acceptable risk.

3. It appears quite possible that - after an initial phase - the burden to the public for maintaining the operation of this type of a lunar laboratory can come down to less than a billion dollar per year which makes this option a very attractive propositon.

4.The big hurdle of a decision to enter a new phase of lunar development is the sizable up-front investment requiring an average of up to 5 billion (1993/94) $ for a 10 year period.This investment can not come from privat sources, it would have to be made by a group of governments interested in the exploration and utilization of extraterrestrial resources for the benefit of the present and future generations.

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APPENDIX 1 : LULAB Model Assumptions

The lunar simulation model used in this analysis is fully documented in the following report:
H.H.Koelle, B.Johenning: "LUNAR BASE SIMULATION"
ILR Mitt.115/1982, Institut für Luft- und Raumfahrt, Technische Universität Berlin, Germany,1.Nov.1982, 205 pages.
In this chapter not the equations, but the required inputs required for the model and the assumptions made for the lunar laboratory option are presented for better transparency of the results obtained in this analysis. This is the only way to find out whether the results obtained and conclusions drawn are trustworthy or not.

1. Inputs for the Lunar Simulation Model:

DEFINITIONS AND CODES OF LUNAR FACILITIES AND MASS FLOWS

Facilities:
01 = strip mine
02 = beneficiation facility
03 = chemical processing facility
04 = mechanical processing facility
05 = fabrication shop
06 = assembly facility
07 = laboratories and scientific equipment
08 = gas mine and equipment
09 = gas prosessing and liquefaction facility
10 = propellant storage for rocket propellants
11 = power plant system on lunar surface including power lines
12 = lunar dump
13 = lunar space-port and equipment
14 = central storage facility other than for rocket propellants
15 = central workshop for maintenance, repair and extensions
16 = central carpool and surface transportation facilities
17 = control center for all lunar facilities and activities
18 = housing facility and offices, incl. health & recreation facilities
19 = biologcal facilities, including biol.waste recycling and food production
20 = lunar solar power satellite in space serving lunar facilities

In case small lunar bases, such as a laboratory with minor production capability are simulated, it is recommended to combine some of these facilities, e.g. :
research facilities = 07, - production facilities = 01+02+03+04+05+06+08+09+19,
infrastructure = 10 + 11+ 12 + 13 + 14 + 15 + 16 + 17 + 20 and housing = 18

Mass flows:

IMPORTS:

m05 = imported chemical required for the production processes
m10 = supplemental materials required for the production prosesses
m15 = supplemental components reqired for fabrication processes
m20 = supplemental subassemblies required for assembly operations
m33 = imported spare-parts
m34 = imported new equipment and facility components for extensions
m41 = imported nitrogen
m42 = imported organic supplies including food and water
m43 = imported anorganic supplies including clothes
m49 = imported operating consumables other than m41,42 and 43
m50 = imported space vehicles and components for salvage

EXPORTS:

m08 = lunar produced raw material for export
m13 = lunar produced construction material for export
m18 = lunar fabricated products for export
m22 = lunar produced assemblies for export
m31 = lunar produced liquid oxygen for export as payloads
m32 = lunar produced liquid oxygen for propulsion purposes
m45 = salvaged parts from space vehicles for export or further use

LUNAR PRODUCTS FOR LUNAR USAGE:

m28 = gases other than oxygen
m29 = GOX for air and water to be used on the Moon
m35 = CO_2 produced by the lunar crew
m36 = organic waste for recycling
m37 = food from the lunar farm
m39 = lunar produced hydrogen
m40 = control propellants produced for lunar space solar power plant
m52 = construction material for lunar consumption
m53 = lunar fabricated products for lunar consumption
m54 = lunar produced construction material for facility extensions
m55 = lunar fabricated products for facility extensions
m56 = lunar produced assemblies for facility extensions
m57 = lunar produced construction material for repairs
m58 = lunar fabricated products for facility repair
m59 = lunar produced assemblies for facility repair

Some of these mass flows may be combined in case these are small as this is likely in research oriented lunar installations.

The following numerical assumptions are required to make a production run of a lunar laboratory with respect to mass flows, operational parameters and cost estimates.

CONTROL VARIABLES

determining the overall performance and size of the lunar base:

Excavated lunar soil for input into the beneficiation module:

year	1	4	10	20	30	40	50
t p.a.	7000.	9000.	9000.	9000.	9000.	9000.	9000.

Gas mine production

year	1	5	10	20	30	40	50
t p.a.	0.	10.	10.	10.	10.	10.	10.

imported space vehicles for salvaging

year	1	50
mass veh.t p.a.	1.	20.

Imported propellants to lunar surface for space and surface vehicles (these determine only the size and mass of the propellant storage facilities)

year	1	5	10	20	30	40	50
t p.a.	500.	500.	500.	500.	500.	500.	500.

scientific crew for operation of research facilities and equipment(the number for the first year must be 1 or larger to obtain cost data)

year	1	5	10	20	30	40	50
persons	2.	12.	20.	35.	45.	50.	50.

In addition to the control variables above the following control variables could also be introduced in the same manner:

lunar propellants required for export;
power level of a solar space power plant in lunar orbit, if any.

Facility masses

The mass of the 20 inidividual facilities are the function of the mass flows per annum through these facilities. The specific masses assumed for each of the facilities are an important input to the model and are selected for the reference case as follows:

01	0.002	0.002	FAC. MASS / EXCAVATED SOIL (MG*Y/MG)
02	0.002	0.0015	" / EXCAVATED SOIL
03	0.075	0.060	" / SOIL + SCRAP INPUT
04	0.60	0.3	" / RAW MATERIAL INPUT
05	1.0	0.3	" / CONSTR. MATERIAL INPUT
06	1.0	0.3	" / FABRIC. PROD. INPUT
07	5.5	4.5	" / LABORATORY CREW
08	0.006	0.005	" / GASEOUS PROD. OUTPUT
09	0.15	0.10	" / GASEOUS PROD. INPUT
10	0.010	0.010	" / PROPELLANT MASS
12	0.00001	0.00001	" / WASTES
13	0.15	0.12	" / IMPORT + EXPORT MASS
14	0.050	0.030	" / IMPORT + LOX + SPARE PART MASS

15	0.4	0.35	"	/ EXTENSION + SPARE PART MASS
19	5.0	6.0	"	/ FOOD PRODUCTION
16	0.00100	0.00050	"	/ SURFACE TRANSP.DEMAND(MG*Y/MG*KM)
17	4.0	3.0	"	/ CREW OF 217 (MG/MAN)
18	2.5	2.5	"	/ LUNAR SURFACE CREW (MG/MAN)
11	0.05	0.025	"	/ NET POWER OF 211 (MG/KW)
20	0.04	0.03	"	/ NET POWER OF 220 (MG/KW)

In case of small lunar facilities this will results in unrealistic small fractional masses in the early years of existance, consequently they have to be corrected by "eyeballing" for the first 3 to 5 years, particularly if whole large modules are delivered by the space transportation system to the lunar base site.

Power demand

All lunar facilies require electric and thermal power,which is different during the day and night cycle, but will be proportional to the mass flow through these facilities and the personnel working in these facilities. Consequently specific power requirements, externally derived or estimated, are required as inputs to the lunar simulation model. The following preliminary estimates have been made for the present lunar laboratory option (first and last year of the LC):

*FAC.	* PARAMETERS OF POWER DEMAND MODEL			
01	0.001	0.0009	POWER DEM.	/ EXCAVATED SOIL (KW*Y/MG)
02	0.0015	0.0013	"	/ EXCAVATED SOIL
03	1.20	1.20	"	/ SOIL + SCRAP INPUT
04	0.50	0.45	"	/ RAW MATERIAL INPUT
05	0.5	0.5	"	/ CONSTR. MATERIAL INPUT
06	0.20	0.15	"	/ FABRIC. PROD. INPUT
07	2.0	1.5	"	/ LABORATORY MASS (KW/MG)
08	0.012	0.012	"	/ GASEOUS PROD. OUTPUT
09	1.5	1.20	"	/ GASEOUS PROD. INPUT
10	0.02	0.015	"	/ PROPELLANT MASS
12	0.	1.	"	/ WASTES
13	0.02	0.012	"	/ IMPORT + EXPORT MASS
14	0.04	0.03	"	/ IMPORT + LOX + SPARE PART MASS
15	0.2	0.15	"	/ EXTENSION + SPARE PART MASS
19	8.	45.	"	/ FOOD PRODUCTION
16	0.0002	0.0002	"	/ SURFACE TRANSP.DEMAND(KW*Y/MG*KM)
17	5.0	5.0	"	/ CREW OF 217 (KW/MAN)
18	3.0	2.7	"	/ LUNAR SURFACE CREW (KW/MAN)
11	0.	1.	"	/ NET POWER OF 211 (-)
20	0.	1.0	"	/ NET POWER OF 220 (-)

Human labor demand

To operate these facilities, manpower = human labor is required for assembly, maintenance and repair, control and modifications or extensions. This labor requirement is a function of the mass flow through each of the facilities determining their size, but also of the complexity of the activities and processes taking place in these facilities. Moreover, they are a function of time, because there will be learning with experience. The first two numbers (after the facility code) of the following table are factors determining the labor productivity in the first and last year of the life-cycle with a non-linear growth function. The second group of numbers allow to take into consideration the relative complexity of the operation which determines the labor requirement to be provided by the central workshop primarily for maintenance and repairs. It is possible also to discriminate between the 1st and the last year of the life-cycle due to progress in the technology used. - The following factors have been used for the preliminary analysis of the lunar laboratory option:

<*FAC. * PARAMETERS OF MANPOWER MODEL FOR OPERATION AND WORKSHOP SERVICES

01	0.00006	0.00004	0.03	0.03	CREW	/ EXCAVATED SOIL
02	0.00003	0.00002	0.03	0.03	"	/ EXCAVATED SOIL
03	0.0090	0.0050	0.08	0.06	"	/ SOIL+SCRAP INPUT
04	0.025	0.005	0.08	0.06	"	/ RAW MAT. INPUT
05	0.16	0.05	0.05	0.04	"	/ CONSTR.MAT.INPUT
06	0.40	0.25	0.06	0.050	"	/ FABR.PROD. INPUT
07	0.00	0.01	0.06	0.050	"	/
08	0.0004	0.00025	0.060	0.060	"	/ GASEOUS OUTPUT
09	0.00055	0.0003	0.1	0.1	"	/ GASEOUS INPUT
10	0.0003	0.00016	0.03	0.03	"	/ LOX + PROP. INP.
12	0.0	1.0	0.0	1.0	"	/ WASTES
13	0.005	0.002	0.05	0.04	"	/ IMPORT + EXPORT
14	0.0058	0.0038	0.03	0.03	"	/ IMPORT + SPARES
15	0.060	0.060	0.06	0.05	"	/ SALVAGED PARTS
19	0.10	0.10	0.02	0.03	"	/ FOOD PRODUCTION
16	0.00010	0.00005	0.03	0.02	"	/ SURFACE TRANSP.
17	0.05	0.032	0.06	0.05	"	/ LUNAR SURF.CREW (-)
18	0.10	0.075	0.03	0.03	"	/ LUNAR SUR.CREW (-)
11	0.001	0.0009	0.10	0.08	"	/ NET POW. 211(M/KW)
20	0.0002	0.00015	0.06	0.04	"	/ NET POW. 220(M/KW)

Transportation demand on lunar surface

(distance between facility and primary point of destination in average km or total annual passenger-kilometers for personnel for the first and last year of the life-cycle)

*FAC. * PARAMETERS OF SURFACE TRANSP. MODEL FOR FREIGHT AND PERSONNEL

facility			cargo(km)		passenger x km p.a.
01	3.	3.	1100.	1100.	DISTANCE (KM) FOR MAIN DESTINATION
02	0.1	0.1	1100.	1100.	
03	1.	1.	330.	330.	
04	1.	1.	330.	330.	
05	2.	2.	110.	110.	
06	6.	6.	110.	110.	
07	3.	3.	550.	550.	
08	0.	1.	1100.	2200.	
09	0.	1.	1100.	1100.	
10	10.	10.	1100.	1100.	
11	20.	20.	660.	660.	
12	0.	1.	0.	1.	
13	10.	10.	1100.	1100.	
14	6.	6.	110.	110.	
15	5.	5.	550.	550.	
16	0.	1.	330.	330.	
17	0.	1.	110.	110.	
18	6.	6.	0.	1.	
19	6.	6.	0.	1.	
20	0.	1.	0.	1.	

Parameters determining the relations between mass flows
(first column = identification, 2nd = first year of life-cycle, 3rd = last year of life-cycle)

<*CAT.	* PARAMETERS OF MODEL FOR MASS FLOWS		
0202	0.95	0.85	SLAG 202 / EXCAVATED SOIL
0503	0.001	0.005	IMPORTED CHEM. 203 / BENEFIC. SOIL
2703	0.40	0.40	GASEOUS PRODUCTS 203 / BENEFIC. SOIL
0601	0.03	0.06	RAW MAT. TO MECH. PROCESSING / INPUT 203
0801	0.01	0.01	RAW MAT. FOR EXPORT / INPUT 203
4603	0.01	0.01	LEAKAGE / INPUT 203
0903	0.010	0.010	RAW MAT.TO STORAGE /INPUT 203 EXCL. SCRAP
1001	0.02	0.01	IMPORTED MAT./ LUNAR RAW MAT. INPUT 204
2104	0.03	0.02	SCRAP / INPUT 204
1201	0.5	0.6	STOCK TO FABRICATION / INPUT 204
4604	0.005	0.002	LEAKAGE / INPUT 204
1501	0.08	0.06	IMPORTED PRODUCTS / STOCK INPUT 205
2105	0.05	0.03	SCRAP / STOCK INPUT 205
1701	0.05	0.30	FABR. PRODUCTS TO ASSEMBLY / INPUT 205
4605	0.01	0.01	LEAKAGE / IMPORTED PROD. FOR 205
2001	0.10	0.08	IMP. COMPONENTS / FABR. PRODUCTS INPUT 206
2106	0.05	0.02	SCRAP / FABR. PRODUCTS INPUT 206
2107	0.60	0.75	SCRAP / TOT. SUPPLIES
4607	0.05	0.05	AIR LEAKAGE / LAB. CREW (MG/Y/MAN)
2907	0.37	0.37	GOX INPUT / AIR LEAKAGE
4307	0.50	0.50	TOT. SUPPLIES / LAB. CREW (MG/Y/MAN)
5307	0.1	0.1	LUNAR FAB. PRODUCTS / LAB. CREW (")
4908	0.001	0.001	IMP. CONSUMABLES 208 / GASEOUS PROD. 208
0108	10.	10.	LUNAR SOIL INPUT / GASEOUS OUTPUT 208
0708	0.8	0.8	ANORGANIC WASTE / INPUT 208
5208	0.001	0.001	LUNAR CONSUM. MAT. / GASEOUS PROD. 208
0409	0.001	0.001	IMPORTED CHEMICALS / LOX OUTPUT 209
0509	0.002	0.001	IMPORTED CHEMICALS / GASEOUS INPUT 209
2909	0.95	0.95	GOX OUTPUT / GASEOUS INPUT 209
4609	0.02	0.01	LEAKAGE / TOTAL INPUT 209
5209	0.001	0.001	LUNAR CONSUM. MAT./ GOX OUTPUT 209
0510	0.001	0.001	IMPORTED CHEMICALS / LOX + PROP. INPUT 210
3210	0.03	0.02	LOX LEAKAGE / LOX INPUT 210
4410	0.03	0.02	PROP. LEAKAGE / PROP. INPUT 210
3001	0.99	0.99	LOX OUTPUT / GOX INPUT 210
2918	0.370	0.370	GOX INPUT / GAS LEAKAGE 218 & 219
2919	0.800	0.800	GOX OUTPUT / CO2 INPUT 219
3618	0.04	0.4	ORGANIC WASTE TO FARM / FOOD INPUT 218
3918	0.12	0.12	LH2 INPUT / WATER LEAKAGE 218 & 219
4219	0.9	0.6	IMPORTED ORG. MATTER / FOOD OUTPUT 219
2118	0.8	0.9	SCRAP / ANORG. CONSUMABLES 218 & 219
4611	0.5	0.3	LEAKAGE / CONSUMABLES INPUT 211
2920	0.370	0.370	GOX INPUT / GAS LEAKAGE 220
3620	0.1	0.1	ORGANIC WASTE TO FARM / FOOD INPUT 220
3201	1.1	1.1	LOX FOR PROP. / PAYLOAD ES-LS VIA LUO
3204	2.6	2.6	LOX FOR PROP. / PAYLOAD ES-LS VIA GEO
3213	2.2	2.2	LOX FOR PROP. / PAYLOAD LS-GEO
3212	1.4	1.4	LOX FOR PROP. / PAYLOAD LS-L1
3220	1.2	1.2	LOX FOR PROP. / PAYLOAD L1-LS

Lunar produced spare parts as share of total sparepart demand

The continuation of this table gives the assumptions for the ratio of
Lunar construction material for repair/spare part demand = 57 + fac.no.
Lunar fabricated products for repair /spare part demand = 58 + fac.no.
Lunar produced assemblies for repair /spare part demand = 59 + fac.no.

fac 1 - 7			fac 8 - 14			fac 9 - 20		
2601	0.05	0.20	2608	0.05	0.20	2615	0.05	0.20
5701	0.05	0.08	5708	0.05	0.1	5715	0.05	0.15
5801	0.05	0.10	5808	0.05	0.20	5815	0.05	0.20
5901	0.05	0.05	5908	0.05	0.10	5915	0.05	0.10
2602	0.05	0.20	2609	0.05	0.20	2616	0.05	0.20
5702	0.05	0.10	5709	0.05	0.10	5716	0.05	0.08
5802	0.05	0.20	5809	0.05	0.20	5816	0.05	0.14
5902	0.05	0.05	5909	0.05	0.10	5916	0.05	0.08
2603	0.05	0.20	2610	0.05	0.20	2617	0.05	0.15
5703	0.05	0.10	5710	0.05	0.15	5717	0.05	0.15
5803	0.05	0.20	5810	0.05	0.10	5817	0.05	0.10
5903	0.05	0.10	5910	0.05	0.05	5917	0.05	0.20
2604	0.05	0.20	2611	0.05	0.20	2618	0.05	0.20
5704	0.05	0.15	5711	0.05	0.10	5718	0.05	0.10
5804	0.05	0.20	5811	0.05	0.20	5818	0.05	0.20
5904	0.05	0.10	5911	0.05	0.10	5918	0.05	0.10
2605	0.05	0.20	2612	0.05	0.5	2619	0.05	0.20
5705	0.05	0.20	5712	0.05	0.5	5719	0.05	0.13
5805	0.05	0.15	5812	0.05	0.5	5819	0.05	0.14
5905	0.05	0.10	5912	0.05	0.5	5919	0.05	0.13
2606	0.05	0.20	2613	0.05	0.20	2620	0.05	0.20
5706	0.05	0.15	5713	0.05	0.20	5720	0.05	0.20
5806	0.05	0.20	5813	0.05	0.20	5820	0.05	0.20
5906	0.05	0.10	5913	0.05	0.10	5920	0.05	0.10
2607	0.05	0.20	2614	0.05	0.20			
5707	0.05	0.10	5714	0.05	0.15			
5807	0.05	0.20	5814	0.05	0.20			
5907	0.05	0.10	5914	0.05	0.10			

continuation of previous table:

4501	0.2	0.5	SALVAGED PARTS FROM STS / VEHICLES FOR SALV.
0715	0.05	0.2	ANORG. WASTE / TOTAL DEFECTIVE EQUIPMENT
4615	0.01	0.005	LEAKAGE / OUTPUT 215
4618	0.05	0.05	TOTAL AIR LEAKAGE / SURFACE CREW *(MG/MAN-Y)*
4619	0.10	0.08	WATER LEAKAGE 218-19 / LUNAR SURFACE CREW
5318	0.01	0.01	LUNAR PROD. CONSUMABLES TO 218 / MAN
3518	0.30	0.30	TOTAL CO2 PRODUCTION / MAN
3818	0.20	0.20	EQUIVALENT MASS / MAN
4218	0.6	0.5	TOTAL FOOD DEMAND / MAN
4318	0.4	0.3	TOTAL CONSUMABLES DEMAND FOR 218 / MAN
4620	0.01	0.01	AIR LEAKAGE 220 / SPS CREW
3720	0.01	0.01	LUNAR PRODUCED FOOD FOR 220 / SPS CREW
5320	0.01	0.01	LUNAR CONSUMABLES PROD. FOR 220 / SPS CREW
4220	0.01	0.01	TOTAL FOOD DEMAND FOR 220 / SPS CREW
4320	0.01	0.01	TOTAL CONSUM. DEMAND FOR 220 / SPS CREW
4916	0.00010	0.00010	IMP. OPERAT.CONSUM. 216 /TRANSP.REQ. *(1/KM)*
5216	0.00002	0.00002	LUN. OPERAT.CONSUM. 216 /TRANSPORTATION REQ.
4911	0.0005	0.00030	IMP. OPERAT.CONSUM. 211 / POWER 211 (MG/Y/KW)
5211	0.00001	0.00001	LUN. OPERAT.CONSUM. 211 / POWER 211

4920	0.001	0.001	IMP. OPERAT.CONSUM. 220 / POWER 220
5220	0.001	0.001	LUN. OPERAT.CONSUM. 220 / POWER 220
4001	0.0	0.0	CONTROL PROPELLANT (LOX) 220 / POWER 220

The ratios of spare-part demand to facility mass in terms of metric tons of total spares (lunar produced plus imported) per annum per metric ton facitily is presented next with the respective numbers for the lunar laboratory option for first and last year of laboratory life-cycle

facilities 1 to 10			facilities 11 to 20		
2501	0.06	0.10	2511	0.05	0.07
2502	0.05	0.10	2512	0.02	0.02
2503	0.05	0.08	2513	0.05	0.08
2504	0.05	0.12	2514	0.02	0.01
2505	0.06	0.05	2515	0.06	0.05
2506	0.05	0.04	2516	0.05	0.10
2507	0.05	0.04	2517	0.04	0.03
2508	0.04	0.03	2518	0.05	0.05
2509	0.05	0.08	2519	0.05	0.05
2510	0.03	0.02	2520	0.06	0.05

Lunar materials for the extension of lunar facilities

The continuation of this table gives the assumptions for the ratio of
Lunar construction material for extension/ext. mass req. = 57 + fac.no.
Lunar fabricated products for extension /ext. mass req. = 58 + fac.no.
Lunar produced assemblies for extension /ext. mass req. = 59 + fac.no.

facilities 1 to 7			facilities 8 to 14			facilities 15 to 20		
5401	0.03	0.10	5408	3.03	0.15	5415	0.03	0.15
5501	0.02	0.05	5508	0.02	0.20	5515	0.02	0.20
5601	0.01	0.05	5608	0.01	0.1	5615	0.01	0.10
5402	0.03	0.10	5409	0.03	0.10	5416	0.03	0.1
5502	0.02	0.20	5509	0.02	0.20	5516	0.02	0.15
5602	0.01	0.02	5609	0.01	0.10	5616	0.01	0.10
5403	0.03	0.15	5410	0.03	0.15	5417	0.03	0.20
5503	0.02	0.15	5510	0.02	0.20	5517	0.02	0.10
5603	0.01	0.20	5610	0.01	0.10	5617	0.01	0.10
5404	0.03	0.15	5411	0.03	0.05	5418	0.03	0.15
5504	0.02	0.20	5511	0.02	0.20	5518	0.02	0.20
5604	0.01	0.10	5611	0.01	0.10	5618	0.01	0.10
5405	0.03	0.20	5412	0.03	0.5	5419	0.03	0.20
5505	0.02	0.20	5512	0.02	0.5	5519	0.02	0.20
5605	0.01	0.10	5612	0.01	0.5	5619	0.01	0.10
5406	0.03	0.10	5413	0.03	0.20	5420	0.03	0.10
5506	0.02	0.20	5513	0.02	0.20	5520	0.02	0.2
5606	0.01	0.10	5613	0.01	0.10	5620	0.01	0.10
5407	0.03	0.15	5414	0.03	0.15			
5507	0.02	0.15	5514	0.02	0.25			
5607	0.01	0.10	5614	0.01	0.10			

ASSUMPTIONS FOR COST ESTIMATES

Assumptions for specific development cost of facilities 1 to 20 in terms of million 1990 $ per element

CM	01	02	03	04	05	06	07	08	09	10
	90.	180.	900.	480.	90.	90.	900.	0.	600.	180.
CM	11	12	13	14	15	16	17	18	19	20
	900.	0.	360.	120.	90.	480.	900.	1200.	840.	0.

Assumptions for specific production cost of facilities 1 to 20 in terms of 1990 $/kg facility mass

SM	01	02	03	04	05	06	07	08	09	10
	380.	400.	600.	2550.	1300.	1500.	1800.	0.	2500.	1450.
SM	11	12	13	14	15	16	17	18	19	20
	3600.	0.	1500.	650.	1250.	1300.	4400.	1800.	850.	0.

Assumptions for specific assembly cost of facilities 1 to 20 in terms of 1990 $/kg facility mass

SA	01	02	03	04	05	06	07	08	09	10
	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SA	11	12	13	14	15	16	17	18	19	20
	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Other specific costs:
SC: Cost of Earth supplies = 30 $/kg
SV: specific cost of salvaged space vehicles parts = 500 $/kg
YA: personnel cost of support labor on Earth = 200. td $/ labor-year
YT: personnel cost of for training of astronauts =200. td/labor-year
YC: salaries for lunar crew mwmbers = 300. td $/lunar labor-year
RE: share of development costs for sustained engineering 0.02
RI: interest rate used for front-end cost = -.5

Time periods:
TB: crew duty period first year = 0.5 years
TE: crew duty period last year = 0.5 years
TP: crew duty cycles total per person on the Moon = 2.0
TT: length of training time per crew member = 1.0 years
TV: length of recuperation period on Earth after lunar duty = 0.25 years
TL: length of simulation of lunar operation = 50 years
DM: number of annual labor-hours per crew member on the Moon = 2200
DO: number of labor hours req. for maintenance of ferries per vehicle= 500
AS: number of persons on Earth for admistrative support = 1000
AT: number of persons on Earth for training support = 200
EPS: greatest allowable change rate between individual iterations = 0.01

Development period of lunar facilities (years):

TD	01	02	03	04	05	06	07	08	09	10
	5.	4.	8.	7.	6.	4.	7.	0.	6.	3.
TD	11	12	13	14	15	16	17	18	19	20
	8.	0.	5.	5.	7.	6.	8.	8.	8.	0.

Assembly and system integration period on the Moon(years)

TA	01	02	03	04	05	06	07	08	09	10
	1.	1.	1.	1.	1.	1.	1.	0.	1.	1.
TA	11	12	13	14	15	16	17	18	19	20
	1.	0.	1.	1.	1.	1.	1.	1.	1.	0.

Annual parameters entering the calculation:

BL = number of lunar bus launches per annum
BO = number of lunar bus overhauls
FRT= roundtrip cost Earth-Moon in 1000 (1990) $/person
FEM= specific cargo transportation cost EARTH - Moon in 1990 $/kg
FML= specific cargo transportation cost lunar spaceport to L1 spaceport in case a facility is in this location = 300 (1990) $/kg
FEL= specific cargo transportation cost Earth spaceport to L1 spaceport in case a facility is in this location =1200 (1990) $/kg

BL	BO	FRT	FEM
0.	1.0	7597.	2877.
5.0	1.0	7597.	2714.
7.0	1.0	7251.	2767.
6.0	1.0	7144.	3563.
5.0	1.0	7500.	3563.
4.0	1.0	7515.	2821.
4.0	1.0	7484.	2801.
4.0	1.0	7441.	2791.
4.0	1.0	7418.	2779.
5.0	1.0	7397.	2760.
5.0	1.0	7350.	2752.
5.0	1.0	7333.	2745.
5.0	1.0	7317.	2728.
5.0	1.0	7282.	2722.
5.0	1.0	7267.	2716.
5.0	1.0	7255.	2711.
5.0	1.0	7239.	2707.
6.0	1.0	7230.	2701.
6.0	1.0	7217.	2655.
6.0	1.0	7119.	2583.
6.0	1.0	6966.	2580.
6.0	1.0	6958.	2576.
6.0	1.0	6950.	2573.
6.0	1.0	6943.	2567.
6.0	1.0	6930.	2553.
6.0	1.0	6900.	2550.
6.0	1.0	6893.	2538.
6.0	1.0	6868.	2537.
6.0	1.0	6865.	2524.
6.0	1.0	6837.	2455.
6.0	1.0	6691.	2444.
7.0	1.0	5772.	2444.
7.0	1.0	5267.	2432.
7.0	1.0	5242.	2429.
7.0	1.0	5249.	2427.
7.0	1.0	5245.	2425.
7.0	1.0	5240.	2423.
7.0	1.0	5236.	2421.
7.0	1.0	5221.	2419.
7.0	1.0	5227.	2146.
7.0	1.0	4633.	1400.
7.0	1.0	3057.	1398.
7.0	1.0	3053.	1396.
7.0	1.0	3049.	1395.
7.0	1.0	3046.	1393.
7.0	1.0	3042.	1392.
7.0	1.0	3037.	1390.
7.0	1.0	3033.	1389.
7.0	1.0	3031.	1388.
7.0	1.0	3028.	1386.
7.0	1.0	3025.	1386.

The costs for lunar base operations are calculated using the specific transportation costs resulting from the estimates of the TRASIM model. Their dimensiones are $/kg cargo and $/passenger roundtrip. These are multiplied with the partial masses and passenger trips resulting from the lunar base model. If done that way, the cost will be less than the actual cost. This can be corrected by applying correction factors.

The correction factor for the specific transportation costs are obtained by deviding the cargo actuallly arriving at the Base (=payload capability * no.cargo flights) by the (minimum) cargo required by the LUBSIM Model.The spec.cargo transportation costs have to be multiplied by this correction factor before inputted into the LUBSIM model.-The spec.pass.trspt.cost have to be corrected in a similar way.Corr.F = Pass.capacity * no.pass.flights/ no. of passengers actually transported.

In case the actual specific transportation costs are introduced into the LUBSIM model, ist will produce the overall cost of the system including the logistic cost.

The following factors are needed in case one wants to determine the commercial cost of lunar products and services. They are not used in this Lunar Outpost option.

QP	01	02	03	04	05	06	07	08	09	10
	1.	1.	300.	750.	1900.	4600.	36.	1.	400.	1.
QP	11	12	13	14	15	16	17	18	19	20
	4000.	1.	85.	1.	45.	2.	40.	15.	18000.	1.

1	FIS	TAX	Z1C	Z2C	Z3C	Z1F	Z3F
	50.0	50.0	2.5	5.0	5.0	5.0	5.0
2							
	50.0	50.0	2.5	5.0	5.0	5.0	5.0
3							
	50.0	50.0	2.5	5.0	5.0	5.0	5.0
4							
	50.0	50.0	2.5	5.0	5.0	5.0	5.0
5							
	50.0	50.0	2.5	5.0	5.0	5.0	5.0
6							
	50.0	50.0	2.5	5.0	5.0	5.0	5.0

APPENDIX 2 : Inputs to the space transportation simulation model (TRASIM)

This simulation model is fully documented in the following report: H.H.Koelle, B.Johenning: "A Multi-Vehicle Space Carrier Fleet Cost Model for a Multi-Mission Scenario", ILR Mitt. 240/1990, Institut für Luft- und Raumfahrt, Technische Universität Berlin, Germany , 1.May 1990, 99 pages. It allows to simulate the cargo and passenger transport between 7 destinations between the Earth and the Moon in various mission modes and in combination of 5 different space vehicles.

This particular mission model selected for the lunar laboratory option is designed in such a way, that the number of HLLV and LUBUS vehicle flights are identical. In doing so, there will be no long waiting times at the LUO-SOC site for transfer of personnel and cargo. The payload capability of the HLLV increases during the life cycle in the process of product improvement activities. In case secondary missions are required for the transportation of spareparts, material,personnel or facilities (e.g.SOC to LUO) the model provides an input table which designates the vehicle which has to provide this service. In the standard case it will do this with 100% of all requirements, but if two different vehicles are available, the share (%) of each has to be given as an input. The number of primary missions plus the number of secondary missions will then be added and represent the total program.

The model begins with the definition of the participating space vehicles. In the case of the Lunar Laboratory Option there are two space vehicles in operation, a "Heavy Lift Launch Vehicle"(HLLV) and a "Lunar Bus"(LUBUS) supported by a space operation center in lunar orbit with the following mass and operational models:

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V E H I C L E   M O D E L Heavy Lift Launch Vehicle

VEHICLE 1		[YEARS]		
	VEHICLE LIFE TIME :	25.	MIXTURE RATIO :	
	OPERATIONAL PERIOD :	50.	6.	
STAGES 3	YEAR OF IOC :	1.	PROD.IMPR. RATE	
	DEVELOPMENT PERIOD :	8.	0.015	

STAGE 1

COMPONENT	MASS [KG] PER UNIT	AREA[M*M] PER UNIT	NO.OF UNITS	MAX. NO. OF REUSES	TYPE INDEX
COLD STRUCT.	304600.0		1	300.	
HOT STRUCT.	22200.0	3200	1	100.	4
FUEL TANK	6150.0		12	150.	
OXID. TANK	4850.0		6	200.	
EQUIPMENT	8900.0		1	150.	
ENGINE	2250.0		40	50.	
RECOVERY EQ.	3175.0		6	150.	
INTERSTAGE	0.0		0	0.	

STAGE 2

COMPONENT	MASS [KG] PER UNIT	AREA[M*M] PER UNIT	NO.OF UNITS	MAX. NO. OF REUSES	TYPE INDEX
COLD STRUCT.	71500.0		1	300.	
HOT STRUCT.	15700.0	1400	1	50.	1
FUEL TANK	3640.0		6	150.	
OXID.TANK	2880.0		3	200.	
EQUIPMENT	3500.0		1	150.	
ENGINE	3150.0		9	50.	
RECOVERY EQ.	920.0		6	100.	
INTERSTAGE	0.0		0	0.	

STAGE 3

COMPONENT	MASS [KG] PER UNIT	AREA[M*M] PER UNIT	NO.OF UNITS	MAX. NO. OF REUSES	TYPE INDEX
COLD STRUCT.	13450.0		1	300.	
HOT STRUCT.	15600.0	420	1	1.	3
FUEL TANK	4630.0		1	150.	
OXID.TANK	252.0		12	200.	
EQUIPMENT	1800.0		1	150.	
ENGINE	2750.0		1	50.	
RECOVERY EQ.	475.0		6	100.	
SHROUD	2500.0		1	1.	

PARAMETERS FOR COST ESTIMATION Heavy Lift Launch Vehicle

			STAGE 1	STAGE 2	STAGE 3
----- DEVELOPMENT COST					
F1	STRUCTURE:	MATERIAL & TECHNOL.	1.2	1.5	1.7
F2	STRUCTURE:	SURFACE CURVATURE	0.8	0.9	0.9
K	TPS:	MATERIAL & TECHNOL.	30.7	19.7	9.3
KW	LH2 TANK:	REUSABILITY	1.3	1.0	1.3
F1	LH2 TANK:	MATERIAL & TECHNOL.	1.0	0.6	1.7
KW	LOX TANK:	REUSABILITY	1.3	1.0	1.3
F1	LOX TANK:	MATERIAL & TECHNOL.	1.0	0.6	1.7
KW	HYDRAULICS:	REUSABILITY	1.0	1.0	1.1
KW	G & CONTROL:	REUSABILITY	1.0	1.0	1.1
KW	COMMUNICAT.:	REUSABILITY	1.0	1.0	1.1
KW	POWER SYST.:	REUSABILITY	1.0	1.0	1.1
KW	ENGINES:	REUSABILITY	1.3	1.3	1.3
F1	ENGINES:	TECHNOLOGY	0.3	0.2	0.4
F2	ENGINES:	RELIABILITY	0.7	0.5	0.4
F3	ENGINES:	EXPERIENCE	0.5	0.3	0.3
F1	RECOVERY S.:	TECHNOLOGY	1.3	1.5	1.7
F2	RECOVERY S.:	SURFACE CURVATURE	0.8	0.9	0.9

----- PRODUCTION COST -----

F1	STRUCTURE:	TECHNOLOGY	1.1	1.3	1.5
F2	STRUCTURE:	SURFACE CURVATURE	0.9	0.9	0.9
F3	STRUCTURE:	ASSEMBLY OPS	1.1	1.1	1.1
F4	STRUCTURE:	COST OF MAT. ($/KG)	10.0	15.0	20.0
F1	TPS/ABL. :	TECHNOLOGY	1.7	1.5	1.3
F2	TPS/ABL. :	SURFACE CURVATURE	0.8	0.8	0.8
F1	TANKS :	TECHNOLOGY	1.1	1.3	1.5
F4	TANKS :	COST OF MAT. ($/KG)	10.0	15.0	30.0
F1	SHROUD :	TECHNOLOGY	1.0	1.0	1.5
F2	SHROUD :	SURFACE CURVATURE	0.8	0.8	0.8
F3	SHROUD :	ASSEMBLY OPS	1.2	1.0	1.2
	ENGINES :	PREPRODUCTION NO.	100.0	100.0	100.0

----- OPERATIONS COST -----

F3	REFURBISHM.:	STRUCTURE TECHNOL.	1.0	1.2	1.0
F5	REFURBISHM.:	ENGINE TECHNOLOGY	1.0	1.0	1.0
F5	REFURBISHM.:	TPS TECHNOLOGY	0.35	1.0	1.4

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* PRODUCTION factors influencing the amount of tooling required
DEVICES : COMPLEXITY FACTOR 1.2
DEVICES : SURFACE CURVAT'JRE FA. 0.8

* OPERATIONAL factors taking into consideration the number of stages
INTEGRATION : STAGE FACTOR 2.0
MISSION CONTROL: STAGE FACTOR 1.0

Space Vehicle No.2: Lunar Landing and Launch Vehicle (LUBUS)

			[YEARS]	
VEHICLE 2	VEHICLE LIFE TIME	:	25.	MIXTURE RATIO :
	OPERATIONAL PERIOD	:	50.	6.
STAGES 1	YEAR OF IOC	:	1.	PROD.IMPR. RATE
	DEVELOPMENT PERIOD	:	7.	0.015

STAGE 1

COMPONENT	MASS [KG] PER UNIT	AREA[M*M] PER UNIT	NO.OF UNITS	MAX. NO. OF REUSES	TYPE INDEX
COLD STRUCT.	3200.0		1	200.	
#HOT STRUCT.	0.0	1	1	1.	1
FUEL TANK	4000.0		1	100.	
OXID.TANK	1000.0		8	150.	
EQUIPMENT	2000.0		1	150.	
ENGINE	350.0		8	50.	
RECOVERY EQ.	0.0		0	0.	
SHROUD	0.0		0	0.	

PARAMETERS FOR COST ESTIMATION — LUBUS

		STAGE 1	STAGE 2	STAGE 3
	DEVELOPMENT COST			
F1	STRUCTURE: MATERIAL & TECHNOL.	1.7	0.0	0.0
F2	STRUCTURE: SURFACE CURVATURE	0.7	0.0	0.0
K	TPS: MATERIAL & TECHNOL.	0.0	0.0	0.0
KW	LH2 TANK: REUSABILITY	1.1	0.0	0.0
F1	LH2 TANK: MATERIAL & TECHNOL.	2.5	0.0	0.0
KW	LOX TANK: REUSABILITY	1.1	0.0	0.0
F1	LOX TANK: MATERIAL & TECHNOL.	2.5	0.0	0.0
KW	HYDRAULICS: REUSABILITY	1.0	0.0	0.0
KW	G & CONTROL: REUSABILITY	0.5	0.0	0.0
KW	COMMUNICAT.: REUSABILITY	0.5	0.0	0.0
KW	POWER SYST.: REUSABILITY	0.5	0.0	0.0
KW	ENGINES: REUSABILITY	1.5	0.0	0.0
F1	ENGINES: TECHNOLOGY	1.2	0.0	0.0
F2	ENGINES: RELIABILITY	1.2	0.0	0.0
F3	ENGINES: EXPERIENCE	0.7	0.0	0.0
F1	RECOVERY S.: TECHNOLOGY	0.2	0.0	0.0
F2	RECOVERY S.: SURFACE CURVATURE	0.5	0.0	0.0
	PRODUCTION COST			
F1	STRUCTURE: TECHNOLOGY	1.0	0.0	0.0
F2	STRUCTURE: SURFACE CURVATURE	0.8	0.0	0.0
F3	STRUCTURE: ASSEMBLY OPS	0.8	0.0	0.0
F4	STRUCTURE: COST OF MAT. ($/KG)	20.0	0.0	0.0
F1	TPS/ABL. : TECHNOLOGY	0.0	0.0	0.0
F2	TPS/ABL. : SURFACE CURVATURE	0.0	0.0	0.0
F1	TANKS : TECHNOLOGY	1.5	0.0	0.0
F4	TANKS : COST OF MAT. ($/KG)	30.0	0.0	0.0
F1	SHROUD : TECHNOLOGY	0.0	0.0	0.0
F2	SHROUD : SURFACE CURVATURE	0.0	0.0	0.0
F3	SHROUD : ASSEMBLY OPS	0.0	0.0	0.0
	ENGINES : PREPRODUCTION NO.	0.0	0.0	0.0
	OPERATIONS COST			
F3	REFURBISHM.: STRUCTURE TECHNOL.	1.2	0.0	0.0
F5	REFURBISHM.: ENGINE TECHNOLOGY	1.2	0.0	0.0
F5	REFURBISHM.: TPS TECHNOLOGY	1.0	0.0	0.0

* PRODUCTION *	
DEVICES : COMPLEXITY FACTOR	1.2
DEVICES : SURFACE CURVATURE FA.	1.0
* OPERATIONS *	
INTEGRATION : STAGE FACTOR	1.0
MISSION CONTROL: STAGE FACTOR	1.0

VEHICLE PAYLOADS: Crew Compartments and cargo containers

P T M DEVELOPMENT PERIOD [YEARS] :	7.	7.	7.
P T M DEVELOPMENT COST FACTOR :	3.0	3.28	3.28

This multiplier above is a cost correction factor which allows to adapt the standard assumption for manned payloads to cost estimates done outside of this model by detailed analysis.

CONTAINER LIFE TIME [YEARS] :

CONTAINER VERSION	PAYLOAD CATEGORY PERS	CARGO	FUEL	OXID	PROP
2	15.0	1.	1.	20.0	20.0
3	15.0	20.0	20.0	20.0	20.0

CONTAINER NET MASS [KG] PER FLIGHT :

CONTAINER VERSION	PAYLOAD CATEGORY PERS	CARGO	FUEL	OXID	PROP
2	25000.0	3000.0	0.0	1000.0	0.0
3	50000.0	5000.0	5000.0	0.0	0.0

CHARACTERISTICS OF THE SPACE OPERATIONS CENTER (SOC)

YEAR OF IOC: 1. NO. OF SOCS: 1
DEVELOPMENT PERIOD: 8. LOC. OF SOCS (NODE): 5 / / / /

SUBSYSTEM	SUBSYSTEM MASS [KG]
PRIMARY STRUCTURE	67000.0
PROPELLANT TANKS	32000.0
FUELLING EQUIPMENT	10000.0
ENGINES	18000.0
STORAGE MODULES	42000.0
CREW QUARTERS	25000.0
GUIDANCE & CONTROL	6000.0
POWER SYSTEM	10000.0
OTHER EQUIPMENT	40000.0

OPERATIONS MODEL OF VEHICLE SYSTEM

RECOVERY COST [MY'S PER MISSION]

VEHICLE	NODE NO. 1	2	3	4	5	6
1	30.0	0.012	0.015	0.015	0.015	0.
2	0.	0.	0.	0.	0.01	0.01

RENT OF SPACE OPERATION CENTERS [MY'S PER MISSION]

UNTIL OP. YEAR	NODE NO. 2	3	4	5	6
10	0.3	0.0	0.0	0.0	1.0
20	0.2	0.0	0.0	0.0	1.0
30	0.1	0.0	0.0	0.0	1.0
40	0.1	0.0	0.0	0.0	0.9
50	0.1	0.0	0.0	0.0	0.8
PERSONNEL STAY TIME IN SPACE [MONTH] :	3.0	6.0	6.0	6.0	6.0

PARAMETERS FOR OPERATIONS COST ESTIMATION

ACTIVITY	ON EARTH	IN SPACE
LAUNCH & MISSION CONTROL	5.0	0.0001
PRELAUNCH OPERATIONS	0.025	0.0002
MANAGEMENT	10.0	0.001
VEHICLE INTEGRATION	0.4	0.0002
GENERAL SUPPORT	20.0	0.002
REFURBISHMENT STRUCTURES	0.010	0.001
REFURBISHMENT ENGINES	0.2	0.004
REFURBISHMENT EQUIPMENT	1.0	0.01
REFURBISHMENT TPS-SYSTEM	0.01	0.0001

REFURBISHMENT COST PER PAYLOAD CONTAINER [MY/MG]

PAYLOAD CATEGORY	ON EARTH	IN SPACE
PERSONNEL	0.05	0.01
CARGO	0.001	0.0001
FUEL (LH2)	0.001	0.0001
OXIDIZER (LOX)	0.001	0.0001
PROPELLANTS	0.001	0.0001

SPECIFIC PROPELLANT PRODUCTION COST [MY/MG] AT POINT OF ORIGIN

PRODUCTION NODE	FUEL	OXIDIZER
1	0.02	0.002
2	0.	0.
3	0.	0.
4	0.	0.
5	0.	0.
6	9.0	3.0

PAYLOAD CATEGORY : 1 = PERSONNEL
2 = CARGO
3 = FUEL (LH2)
4 = OXIDIZER (LOX)
5 = PROPELLANTS (LH2/LOX)

NODE IDENTIFICATION : 1 ES
(3 CHARACTERS) 2 LEO
3 GEO
4 L1
5 LUO
6 LUS

COST OF MANPOWER : 200000.0 $/MY DEVELOPMENT
200000.0 $/MY PRODUCTION
200000.0 $/MY OPERATIONS

COST OF GROUND FACILITIES : VEHILCLE	COST/UNIT [MY]
1	8824.0
2	0.0

AMORTIZATION PERIOD OF GROUND FACILITIES : 25.0 YEARS
AMORTIZATION PERIOD OF SPACE OP. CENTERS : 25.0 YEARS

AMORTIZATION OF DEVELOPMENT COST:
(NUMBER OF FLIGHTS)

	VEHICLE 1	VEHICLE 2
VEHICLE DEVELOPMENT COST	250.	250.
ANNUAL COST OF SUST. ENGIN.	5.	5.

PAYLOAD CATEGORY	1	2	3	4	5
CONTAINER DEVELOPM. COST					
VERSION 2	100.	200.	100.	100.	100.
VERSION 3	100.	200.	100.	100.	100.

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SPACE VEHICLE MISSION MODES

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Heavy Lift Launch Vehicle
VEHICLE : 1
M.MODES : 8 (only 2 used)
M.MODE FOR OUTPUT : 6

MISSION MODE	NODES (FROM-TO)	P/L CAT.	CONT. VERS.	P/L [MG]; [MEN]	P/L NODE OF ORIGIN	MISSION RELIAB. [%]
1	1 - 2	2	2	328.0	1	99.00
2	1 - 3	2	2	114.0	1	98.00
3	1 - 5	3	3	80.0	1	99.00
4	1 - 5	4	3	80.0	1	97.00
5	1 - 5	5	2	68.0	1	96.70
6	1 - 5	1	3	40.0	1	98.70
7	1 - 5	2	2	70.0	1	98.00
8	1 - 5	2	2	85.0	1	98.00

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MISSION SUPPLY REQUIREMENTS ON EARTH & IN SPACE [MG PER MISSION]

MISSION MODE	AT NODE	FROM NODE	MATERIAL	FUEL (LH2)	OXID. (LOX)	PROPELL. (LH2/LOX)
* 6	1	1	29.700	0.	0.	4960.0
6	5	1	0.1	0.	0.	0.0
6	5	6	0.	0.	0.	0.
6	5	1	0.0	0.	0.	0.
* 8	1	1	28.700	0.	0.	4960.0
8	5	6	0.	0.	0.	0.
8	5	1	0.1	0.	0.	0.
8	5	1	0.2	0.	0.	0.

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LEARNING FACTORS (LF) FOR GROUND & SPACE OPERATIONS

ACTIVITY	CUM.MISSIONS FOR LF1	CUM.MISSIONS FOR LF2	LEARNING FACTORS ON EARTH STAGE 1 LF1	STAGE 1 LF2	STAGE 2 LF1	STAGE 2 LF2	STAGE 3 LF1	STAGE 3 LF2	IN SPACE LF1	IN SPACE LF2
PRELAUNCH	100	1000	0.95	0.95	0.95	0.95	0.95	0.95	0.98	0.99
INTEGRAT.	100	1000	0.95	0.95	0.95	0.95	0.95	0.95	0.98	0.99
RF STRUCT.	100	1000	0.95	0.95	0.95	0.95	0.95	0.95	0.98	0.99
RF ENGINES	100	1000	0.95	0.95	0.95	0.95	0.95	0.95	0.98	0.99
RF EQUIPM.	100	1000	0.95	0.95	0.95	0.95	0.95	0.95	0.98	0.99
RF TPS	100	1000	0.95	0.95	0.95	0.95	0.95	0.95	0.98	0.99
RF PL-CON.	100	1000	0.95	0.95	0.95	0.95	0.95	0.95	0.98	0.99
RECOVERY	100	1000	0.95	0.95	0.95	0.95	0.95	0.95	0.98	0.99

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SPACE VEHICLE MISSION MODES

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LUBUS

VEHICLE no. 2

M.MODES : 7 (only 2 used for roundtrips)

M.MODE FOR OUTPUT : 3

MISSION MODE	NODES (FROM-TO)	P/L CAT.	CONT. VERS.	P/L [MG]; [MEN]	P/L NODE OF ORIGIN	MISSION RELIAB. [%]
1	5 - 6	2	2	70.	1	99.50
2	5 - 6	2	2	70.	1	99.00
3	5 - 6	1	2	40.	1	99.50
4	6 - 5	4	2	70.	6	99.50
5	6 - 3	2	2	100.	6	99.50
6	6 - 3	5	2	62.	6	99.50
7	6 - 5	5	2	70.	6	99.50

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MISSION SUPPLY REQUIREMENTS ON EARTH & IN SPACE [MG PER MISSION]

MISSION MODE	AT NODE	FROM NODE	MATERIAL	FUEL (LH2)	OXID. (LOX)	PROPELL. (LH2/LOX)
* 2	5	1	0.2	0.	0.	0.
2	6	6	0.	0.	0.	0.
2	5	1	0.0	0.	0.	0.
2	6	6	0.1	0.	85.	0.
* 3	5	1	0.2	0.	0.	0.
3	5	6	0.	0.	60.	0.
3	6	6	0.1	0.	0.	0.
3	5	0	0.	0.	0.	0.

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LEARNING FACTORS (LF) FOR GROUND & SPACE OPERATIONS

ACTIVITY	CUM.MISSIONS FOR LF1	CUM.MISSIONS FOR LF2	LEARNING FACTORS ON EARTH STAGE 1 LF1	STAGE 1 LF2	STAGE 2 LF1	STAGE 2 LF2	STAGE 3 LF1	STAGE 3 LF2	IN SPACE LF1	IN SPACE LF2
PRELAUNCH	100	1000	0.90	0.95	0.90	0.95	0.90	0.95	0.95	0.95
INTEGRAT.	100	1000	0.90	0.95	0.90	0.95	0.90	0.95	0.95	0.95
RF STRUCT.	100	1000	0.90	0.95	0.90	0.95	0.90	0.95	0.95	0.95
RF ENGINES	100	1000	0.90	0.95	0.90	0.95	0.90	0.95	0.95	0.95
RF EQUIPM.	100	1000	0.90	0.95	0.90	0.95	0.90	0.95	0.95	0.95
RF TPS	100	1000	0.90	0.95	0.90	0.95	0.90	0.95	0.95	0.95
RF PL-CON.	100	1000	0.90	0.95	0.90	0.95	0.90	0.95	0.95	0.95
RECOVERY	100	1000	0.90	0.95	0.90	0.95	0.90	0.95	0.95	0.95

M I S S I O N   M O D E L

Heavy Lift Launch Vehicle   NO. OF MISSIONS / YEAR -(PRIMARY MISSIONS)

M. MODE	1	2	7	8	4	3	6	5
CATEG.	2	2	2	2	3	1	1	3
LEG	1 - 2	1 - 3	1 - 5	1 - 5	1 - 3	1 - 3	1 - 5	1 - 5
YEAR								
1	0	0	0	9	0	0	1	0
2	0	0	0	6	0	0	2	0
3	0	0	0	6	0	0	2	0
4	0	0	0	3	0	0	2	0
5	0	0	0	2	0	0	2	0
6	0	0	0	2	0	0	2	0
7	0	0	0	2	0	0	2	0
8	0	0	0	2	0	0	2	0
9	0	0	0	2	0	0	3	0
10	0	0	0	2	0	0	3	0
11	0	0	0	2	0	0	3	0
12	0	0	0	2	0	0	3	0
13	0	0	0	2	0	0	3	0
14	0	0	0	2	0	0	3	0
15	0	0	0	2	0	0	3	0
16	0	0	0	2	0	0	3	0
17	0	0	0	2	0	0	3	0
18	0	0	0	2	0	0	4	0
19	0	0	0	2	0	0	4	0
20	0	0	0	2	0	0	4	0
21	0	0	0	2	0	0	4	0
22	0	0	0	2	0	0	4	0
23	0	0	0	2	0	0	4	0
24	0	0	0	2	0	0	4	0
25	0	0	0	2	0	0	4	0
26	0	0	0	2	0	0	4	0
27	0	0	0	2	0	0	4	0
28	0	0	0	2	0	0	4	0
29	0	0	0	2	0	0	4	0
30	0	0	0	2	0	0	5	0
31	0	0	0	2	0	0	5	0
32	0	0	0	2	0	0	5	0
33	0	0	0	2	0	0	5	0
34	0	0	0	2	0	0	5	0
35	0	0	0	2	0	0	5	0
36	0	0	0	2	0	0	5	0
37	0	0	0	2	0	0	5	0
38	0	0	0	2	0	0	5	0
39	0	0	0	2	0	0	5	0
40	0	0	0	2	0	0	5	0
41	0	0	0	2	0	0	5	0
42	0	0	0	2	0	0	5	0
43	0	0	0	2	0	0	5	0
44	0	0	0	2	0	0	5	0
45	0	0	0	2	0	0	5	0
46	0	0	0	2	0	0	5	0
47	0	0	0	2	0	0	5	0
48	0	0	0	2	0	0	5	0
49	0	0	0	2	0	0	5	0
50	0	0	0	2	0	0	5	0

M I S S I O N   M O D E L

H S F Distribution of SECONDARY MISSIONS % OF MISSIONS / YEAR

M. MODE	1	2	7	8	4	3	6	5
CATEG.	2	2	2	2	4	3	1	5
LEG	1 - 2	1 - 3	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5
YEAR								
1	0	0	0	100	0	0	100	0
2	0	0	0	100	0	0	100	0
3	0	0	0	100	0	0	100	0
4	0	0	0	100	0	0	100	0
5	0	0	0	100	0	0	100	0
6	0	0	0	100	0	0	100	0
7	0	0	0	100	0	0	100	0
8	0	0	0	100	0	0	100	0
9	0	0	0	100	0	0	100	0
10	0	0	0	100	0	0	100	0
11	0	0	0	100	0	0	100	0
12	0	0	0	100	0	0	100	0
13	0	0	0	100	0	0	100	0
14	0	0	0	100	0	0	100	0
15	0	0	0	100	0	0	100	0
16	0	0	0	100	0	0	100	0
17	0	0	0	100	0	0	100	0
18	0	0	0	100	0	0	100	0
19	0	0	0	100	0	0	100	0
20	0	0	0	100	0	0	100	0
21	0	0	0	100	0	0	100	0
22	0	0	0	100	0	0	100	0
23	0	0	0	100	0	0	100	0
24	0	0	0	100	0	0	100	0
25	0	0	0	100	0	0	100	0
26	0	0	0	100	0	0	100	0
27	0	0	0	100	0	0	100	0
28	0	0	0	100	0	0	100	0
29	0	0	0	100	0	0	100	0
30	0	0	0	100	0	0	100	0
31	0	0	0	100	0	0	100	0
32	0	0	0	100	0	0	100	0
33	0	0	0	100	0	0	100	0
34	0	0	0	100	0	0	100	0
35	0	0	0	100	0	0	100	0
36	0	0	0	100	0	0	100	0
37	0	0	0	100	0	0	100	0
38	0	0	0	100	0	0	100	0
39	0	0	0	100	0	0	100	0
40	0	0	0	100	0	0	100	0
41	0	0	0	100	0	0	100	0
42	0	0	0	100	0	0	100	0
43	0	0	0	100	0	0	100	0
44	0	0	0	100	0	0	100	0
45	0	0	0	100	0	0	100	0
46	0	0	0	100	0	0	100	0
47	0	0	0	100	0	0	100	0
48	0	0	0	100	0	0	100	0
49	0	0	0	100	0	0	100	0
50	0	0	0	100	0	0	100	0

M I S S I O N   M O D E L

LUBUS	NO. OF MISSIONS (PRIMARY MISSIONS)/ YEAR							
M. MODE	1	2	3	4	5	6	7	8
CATEG.	2	2	1	2	2	5	2	5
LEG	5 - 6	5 - 6	5 - 6	6 - 5	6 - 3	6 - 3	3 - 6	3 - 6
YEAR								
1	0	4	1	0	0	0	0	0
2	0	5	2	0	0	0	0	0
3	0	4	2	0	0	0	0	0
4	0	3	2	0	0	0	0	0
5	0	2	2	0	0	0	0	0
6	0	2	2	0	0	0	0	0
7	0	2	2	0	0	0	0	0
8	0	2	2	0	0	0	0	0
9	0	2	3	0	0	0	0	0
10	0	2	3	0	0	0	0	0
11	0	2	3	0	0	0	0	0
12	0	2	3	0	0	0	0	0
13	0	2	3	0	0	0	0	0
14	0	2	3	0	0	0	0	0
15	0	2	3	0	0	0	0	0
16	0	2	3	0	0	0	0	0
17	0	2	3	0	0	0	0	0
18	0	2	4	0	0	0	0	0
19	0	2	4	0	0	0	0	0
20	0	2	4	0	0	0	0	0
21	0	2	4	0	0	0	0	0
22	0	2	4	0	0	0	0	0
23	0	2	4	0	0	0	0	0
24	0	2	4	0	0	0	0	0
25	0	2	4	0	0	0	0	0
26	0	2	4	0	0	0	0	0
27	0	2	4	0	0	0	0	0
28	0	2	4	0	0	0	0	0
29	0	2	4	0	0	0	0	0
30	0	2	5	0	0	0	0	0
31	0	2	5	0	0	0	0	0
32	0	2	5	0	0	0	0	0
33	0	2	5	0	0	0	0	0
34	0	2	5	0	0	0	0	0
35	0	2	5	0	0	0	0	0
36	0	2	5	0	0	0	0	0
37	0	2	5	0	0	0	0	0
38	0	2	5	0	0	0	0	0
39	0	2	5	0	0	0	0	0
40	0	2	5	0	0	0	0	0
41	0	2	5	0	0	0	0	0
42	0	2	5	0	0	0	0	0
43	0	2	5	0	0	0	0	0
44	0	2	5	0	0	0	0	0
45	0	2	5	0	0	0	0	0
46	0	2	5	0	0	0	0	0
47	0	2	5	0	0	0	0	0
48	0	2	5	0	0	0	0	0
49	0	2	5	0	0	0	0	0
50	0	2	5	0	0	0	0	0

M I S S I O N   M O D E L

LUBUS Distribution of SECONDARY MISSIONS % OF MISSIONS / YEAR

M. MODE	1	2	3	4	5	6	7	8
CATEG.	2	2	1	4	2	5	5	5
LEG	5 - 6	5 - 6	5 - 6	6 - 5	6 - 3	6 - 3	6 - 5	3 - 6
YEAR								
1	100	0	100	0	0	100	100	100
2	100	0	100	0	0	100	100	100
3	100	0	100	0	0	100	100	100
4	100	0	100	0	0	100	100	100
5	0	100	100	0	0	100	100	100
6	0	100	100	0	0	100	100	100
7	0	100	100	0	0	100	100	100
8	0	100	100	0	0	100	100	100
9	0	100	100	0	0	100	100	100
10	0	100	100	0	0	100	100	100
11	0	100	100	0	0	100	100	100
12	0	100	100	0	0	100	100	100
13	0	100	100	0	0	100	100	100
14	0	100	100	0	0	100	100	100
15	0	100	100	0	0	100	100	100
16	0	100	100	0	0	100	100	100
17	0	100	100	0	0	100	100	100
18	0	100	100	0	0	100	100	100
19	0	100	100	0	0	100	100	100
20	0	100	100	0	0	100	100	100
21	0	100	100	0	0	100	100	100
22	0	100	100	0	0	100	100	100
23	0	100	100	0	0	100	100	100
24	0	100	100	0	0	100	100	100
25	0	100	100	0	0	100	100	100
26	0	100	100	0	0	100	100	100
27	0	100	100	0	0	100	100	100
28	0	100	100	0	0	100	100	100
29	0	100	100	0	0	100	100	100
30	0	100	100	0	0	100	100	100
31	0	100	100	0	0	100	100	100
32	0	100	100	0	0	100	100	100
33	0	100	100	0	0	100	100	100
34	0	100	100	0	0	100	100	100
35	0	100	100	0	0	100	100	100
36	0	100	100	0	0	100	100	100
37	0	100	100	0	0	100	100	100
38	0	100	100	0	0	100	100	100
39	0	100	100	0	0	100	100	100
40	0	100	100	0	0	100	100	100
41	0	100	100	0	0	100	100	100
42	0	100	100	0	0	100	100	100
43	0	100	100	0	0	100	100	100
44	0	100	100	0	0	100	100	100
45	0	100	100	0	0	100	100	100
46	0	100	100	0	0	100	100	100
47	0	100	100	0	0	100	100	100
48	0	100	100	0	0	100	100	100
49	0	100	100	0	0	100	100	100
50	0	100	100	0	0	100	100	100

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VEHICLE PRODUCTION RATES (1 = HLLV, 2 = LUBUS)

YEAR	I	1	2			
1	I	1.	4.	0.	0.	0.
2	I	1.	0.	0.	0.	0.
3	I	0.	0.	0.	0.	0.
4	I	1.	0.	0.	0.	0.
5	I	0.	1.	0.	0.	0.
6	I	1.	0.	0.	0.	0.
7	I	0.	0.	0.	0.	0.
8	I	0.	1.	0.	0.	0.
9	I	1.	0.	0.	0.	0.
10	I	0.	0.	0.	0.	0.
11	I	0.	0.	0.	0.	0.
12	I	1.	0.	0.	0.	0.
13	I	0.	0.	0.	0.	0.
14	I	0.	0.	0.	0.	0.
15	I	0.	0.	0.	0.	0.
16	I	0.	0.	0.	0.	0.
17	I	0.	0.	0.	0.	0.
18	I	0.	0.	0.	0.	0.
19	I	0.	1.	0.	0.	0.
20	I	0.	0.	0.	0.	0.
21	I	0.	0.	0.	0.	0.
22	I	0.	0.	0.	0.	0.
23	I	0.	0.	0.	0.	0.
24	I	1.	1.	0.	0.	0.
25	I	0.	1.	0.	0.	0.
26	I	1.	1.	0.	0.	0.
27	I	0.	1.	0.	0.	0.
28	I	1.	0.	0.	0.	0.
29	I	0.	0.	0.	0.	0.
30	I	1.	0.	0.	0.	0.
31	I	0.	0.	0.	0.	0.
32	I	1.	0.	0.	0.	0.
33	I	0.	0.	0.	0.	0.
34	I	0.	0.	0.	0.	0.
35	I	0.	0.	0.	0.	0.
36	I	0.	0.	0.	0.	0.
37	I	0.	0.	0.	0.	0.
38	I	0.	0.	0.	0.	0.
39	I	0.	0.	0.	0.	0.
40	I	0.	0.	0.	0.	0.
41	I	0.	0.	0.	0.	0.
42	I	0.	0.	0.	0.	0.
43	I	0.	0.	0.	0.	0.
44	I	0.	0.	0.	0.	0.
45	I	0.	0.	0.	0.	0.
46	I	0.	0.	0.	0.	0.
47	I	0.	0.	0.	0.	0.
48	I	0.	0.	0.	0.	0.
49	I	0.	0.	0.	0.	0.
50	I	0.	0.	0.	0.	0.

FAILURE RATES (CATASTROPHIC) :

VEH.	I	NO.OF RATES	I	RATE	UNTIL OP.YEAR	I	RATE	UNTIL OP.YEAR	I	RATE	UNTIL OP.YEAR
1	I	3	I	0.005	10	I	0.004	20	I	0.003	100
2	I	3	I	0.004	10	I	0.003	20	I	0.002	100

MINIMUM ALLOWABLE VEHICLE LAUNCH INTERVALL ON EARTH [DAYS] :

VEH. 1	I	VEH. 2	I
7.30	I	0.00	I

CONTAINER TURN-AROUND TIME [DAYS] :

VERSION	I	PAYLOAD CATEGORY PERS	CARGO	FUEL	OXID	PROP
2	I	4.0	8.0	8.0	1.0	3.0
3	I	10.0	6.0	2.0	6.0	3.0

LEARNING IN CONTAINER PRODUCTION & SPARE PARTS DEMAND :

LF.= LEARNING FACTOR
NO.= CUM. UNITS PRODUCED
SF.= SPARE PART FACTOR [%]

PAYLOAD CATEGORY	I	LF.	NO.	LF.	NO.	I	SF.[%]	LF.
PESONNEL	I	0.90	100.	0.95	1000.	I	1.5	0.95
CARGO	I	0.90	100.	0.95	1000.	I	0.1	0.95
FUEL	I	0.90	100.	0.95	1000.	I	0.1	0.95
OXIDIZER	I	0.90	100.	0.95	1000.	I	0.1	0.95
PROPELLANTS	I	0.90	100.	0.95	1000.	I	0.1	0.95

LEARNING IN VEHICLE PRODUCTION & SPARE PARTS DEMAND : HLLV

STAGE 1

LF.= LEARNING FACTOR
NO.= CUM. UNITS PRODUCED
SF.= SPARE PART FACTOR PER FLIGHT[%]

PER FLIGHT

COMPONENT	I	LF.	NO.	LF.	NO.	I	SF.[%]	LF.
STRUCTURE	I	0.90	100.	0.95	300.	I	1.5	0.95
TPS	I	0.90	100.	0.95	300.	I	1.0	0.95
TANK FUEL	I	0.90	200.	0.95	500.	I	0.5	0.95
TANK OX.	I	0.90	200.	0.95	500.	I	0.5	0.95
EQUIPMENT	I	0.90	100.	0.95	300.	I	1.0	0.95
ENGINE	I	0.85	300.	0.90	1000.	I	1.5	0.90
RECOV. EQ.	I	0.90	100.	0.95	300.	I	1.0	0.95
SHROUD	I	0.90	100.	0.95	300.	I	1.0	0.95

STAGE 2

LF.= LEARNING FACTOR
NO.= CUM. UNITS PRODUCED

SF.= SPARE PART FACTOR [%] PER FLIGHT

COMPONENT	I	LF.	NO.	LF.	NO.	I	SF.[%]	LF.
STRUCTURE	I	0.90	100.	0.95	300.	I	1.5	0.95
TPS	I	0.90	100.	0.95	300.	I	3.0	0.95
TANK FUEL	I	0.90	200.	0.95	500.	I	0.5	0.95
TANK OX.	I	0.90	200.	0.9.	500.	I	0.5	0.95
EQUIPMENT	I	0.90	100.	0.95	300.	I	1.0	0.95
ENGINE	I	0.85	300.	0.90	1000.	I	1.5	0.85
RECOV. EQ.	I	0.90	100.	0.95	300.	I	1.0	0.95
SHROUD	I	0.90	100.	0.95	300.	I	1.0	0.95

STAGE 3

LF.= LEARNING FACTOR
NO.= CUM. UNITS PRODUCED

SF.= SPARE PART FACTOR [%] PER FLIGHT

COMPONENT	I	LF.	NO.	LF.	NO.	I	SF.[%]	LF.
STRUCTURE	I	0.90	100.	0.95	300.	I	1.5	0.95
TPS	I	0.90	100.	0.95	300.	I	0.1	0.95
TANK FUEL	I	0.90	100.	0.95	500.	I	0.5	0.95
TANK OX.	I	0.90	100.	0.95	500.	I	0.5	0.95
EQUIPMENT	I	0.90	100.	0.95	300.	I	2.0	0.95
ENGINE	I	0.85	300.	0.95	1000.	I	1.5	0.85
RECOV. EQ.	I	0.90	100.	0.95	300.	I	1.0	0.95
SHROUD	I	0.90	100.	0.95	300.	I	1.0	0.95

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LEARNING IN VEHICLE PRODUCTION & SPARE PARTS DEMAND : LUBUS

STAGE 1

LF.= LEARNING FACTOR
NO.= CUM. UNITS PRODUCED

SF.= SPARE PART FACTOR [%] PER FLIGHT

COMPONENT	I	LF.	NO.	LF.	NO.	I	SF.[%]	LF.
STRUCTURE	I	0.95	200.	0.95	300.	I	1.0	0.90
TPS	I	1 0	200.	1.0	300.	I	0.	0.90
TANK FUEL	I	0.95	300.	0.95	500.	I	0.5	0.90
TANK OX.	I	0.95	300.	0.95	500.	I	0.5	0.90
EQUIPMENT	I	0.95	100.	0.95	300.	I	2.0	0.90
ENGINE	I	0.90	300.	0.92	1000.	I	2.0	0.90
RECOV. EQ.	I	0.95	100.	0.95	300.	I	1.0	0.90
SHROUD	I	1.0	100.	1.0	300.	I	0.	0.90