PART II

A WORLD OF COMPLEX PROJECTS – THEN AND NOW

2.1

THE IAI LAVI PROJECT – THE DREAM AND DOWNFALL

An interview with Prof. Ovadia Harari of Blessed Memory

During the second half of the 1970s, the Israeli Air Force had had four main types of attack aircraft: two single-engine fighters, the Skyhawk and the Delta; the Shachak, Nesher, and Kfir models; the two-engine Phantom; and their leading model, the two-engine F15. Around that time, the Air Force began to see the need to replace the Skyhawks and the Deltas with a more advanced, single-engine aircraft.

Israel Aerospace Industries, the company in charge of producing the Nesher and Kfir models, understood that the day when these types of aircraft would no longer be in demand was not far off and was preparing to face the task of developing a new fighter plane.

These preparations were not being made in response to a specific request made by a client. The discourse concerning the need for a new aircraft never went beyond the spontaneous, informal expression of ideas and standpoints between high-ranking Air Force officers. Naturally, these officers maintained continuous contact with IAI, and so, inevitably, word traveled. In other words, because the Air Force had not presented any formal request or demand for the production of such an aircraft, it was impossible to tell what sort of performance it was required to deliver. Moreover, whether the need would even be realized remained unclear. For instance, the Israeli government might

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not have approved an order for a new plane, be it from an Israeli manufacturer or a foreign one.

2.1.1 THE FEASIBILITY STUDY

Despite the uncertainty, IAI was prepared to take a calculated risk. The company wanted to be ready for the (in its estimate, fairly likely) scenario where a demand for the development and production of a new aircraft would indeed be made. At the same time, it wanted to prove that it was capable of accomplishing such a task. So, the management of IAI decided to perform a feasibility study of the new aircraft's design and production.

The task of performing the study was placed on the Department of Preliminary Planning, a part of the Engineering Division. In the words of Ovadia Harari, who then headed the department, its job was "to sprout new ideas and examine solutions without there being anyone to place an order for the product."

But how can one provide solutions, if one does not know the problems?

Harari: "We defined the needs ourselves. We prepared a requirements document based on two main sources of information: first, we held discussions with Air Force officers. This allowed us to assess their needs in relation to the new aircraft. Second, we, as a professional department, were familiar with the capabilities of the aircrafts that existed at the time. We knew the performance they could deliver, and which technological elements we would need to use to improve on that performance. We reverse engineered existing aircraft models (reverse engineering is taking an existing product apart to study its inner workings and to figure out how to make similar products – the authors)."

A feasibility study is not a carefully planned, well-organized process, because there is no client to define the needs and requirements. There is therefore no strict timetable and essentially no budget constraints. The role of "client" was filled by the IAI management, whose only demand was that the department estimate what the potential user might want.

When a client is present, this task naturally falls under the responsibility of his people. Had this been the case, the Air Force project manager would have prepared a base document and distributed it among the relevant officers within the Air Force. Each relevant position holder would then have expressed his opinion on the matter, and eventually, they would all have met and discussed it. The project manager would have served as a mediator and coordinator between the Air Force's various professional units, and the process would have resulted in a balanced requirements document submitted to the company undertaking the project.

Harari: "Our client did not speak with one, cohesive voice (because the Air Force had not yet formulated a concrete position on the matter), so we had to present the management of IAI with the full range of opinions we had heard from the Air Force. For example, one specialist officer believed the aircraft should have a certain flight range, while another was willing to settle for a shorter one, so long as the plane had a more accurate arming system."

The information gathered by the feasibility study team (a team of 5, led by Harari) allowed it to take the first step in the process of defining the new aircraft's configuration, namely, its size.

The size of an aircraft is a very important base parameter. The size affects the plane's capabilities (such as speed and flight range). The type and nature of such subsystems as the engine, radar, flight control, and electronic warfare (EW) are also derived from the size. Of course, the size also has a direct effect on the total cost of the project.

In the beginning of the process, various configurations were considered, including both single and two engine options. The cost was the main reason for the decision not to make a two-engine aircraft (a Lion) to replace the F15. Producing a two-engine fighter plane is a mission of enormous proportions, its costs so high that only a handful of countries in the whole world are able to take it up (all of them, obviously, much larger than Israel).

The need to determine the types of the plane's subsystems drove the team to meet with various experts in IAI. These were leading experts in the professional departments that specialized in each of the relevant systems.

The Political Aspect

As the team was preparing the future aircraft's technical specification, the management of IAI was hard at work on the political level, attempting to urge the Air Force to place an order for the project with IAI. This was a complex task, because whether or not the order was placed did not depend solely on the potential client – the Air Force – but on two other important factors: the Israeli government and the US Department of Defense.

Ovadia Harari, who had later become the right-hand man of IAI's CEO, explains the situation: “The cost of that development project could easily have reached two billion NIS or more (with over 200 planes acquired, the sum would have climbed up to around 20 billion NIS). All projects that approach the cost of one billion NIS immediately gain a political aspect, because they require considerable resource allocations from the state budget. In situations like these, the question of ‘how much will this cost’ is not the only one asked. It is accompanied by such questions as ‘how many people will this provide employment for.’

On top of that, the politicians needed to talk to the US Department of Defense, because Israel cannot develop aircraft engines – the cost of such projects is beyond its financial reach; there can never be an aircraft of pure Israeli origin. So, to design the new aircraft, we needed to receive information about engines, which required the approval of the US authorities. The US manufacturers of aircraft engines, General Electric and Pratt & Whitney, do not give out attack aircraft engine specifications without the approval of the Department of Defense. Had IAI made the request without such an approval, the Department of Defense would have launched a painfully thorough investigation and probably refused us outright. The company needed political support and backing. Otherwise, why would the Americans help IAI? After all, it would be more profitable for them if the Israeli Ministry of Defense bought the plane from an American company."

Back then, over 30 years before these lines were written, the question of cost in military projects was nowhere near as important as it is today. At the time, projects were priced using the "cost plus" method. This meant that the client paid for the development, however much it ended up costing. No finite budget was determined. Nevertheless, the financial question weighed heavily even on the members of the feasibility study team, due to the project's extraordinarily high cost prediction.

Harari: "The very fact that our goal was to develop a plane to replace the Kfir and the Skyhawk and not the F15 stemmed from the cost issue. Meeting the various needs of the military is much easier with a large aircraft. In aeronautics, you control the money through size. The cost of a plane is a function of its size and weight."

The technical specification for the Lavi fighter aircraft was slowly coming into being, taking into account the various needs and constraints, including the cost limitations. Beyond the definition of the plane's configuration and capabilities (flight distance, load capacity, etc.), systems were adjusted using trade-offs.

Explanation: one of the main objectives of systems engineering is to optimize systems by making trade-offs. For example, it is possible to install a more powerful engine, but then the plane would need to be made larger; or, the radar system could be upgraded to a more advanced one, but the new system would weigh more, which would put a heavier load on the aircraft.

Several months after the process had been initiated, a breakthrough occurred, which dramatically raised the chances of the project being realized by IAI.

Ovadia Harari: "The Minister of Defense (along with the IAF Commander) decided to visit IAI, and we presented the project to him. Although I was not a management member at the time, I attended the meeting as an expert, there to answer professional questions. Note that both Defense Ministers who had been involved with the project had some knowledge of the area (Ezer Weizmann, who was in office when the project was announced, was himself a former IAF Commander; while Moshe Arens, an aeronautical engineer and a professor at the Technion, had served as Vice President of IAI in the past – the authors). At the end of the meeting, Ezer Weizmann said the words that made our day, or rather, our year: 'I find this project interesting. I will handle the political aspect and talk to the US Defense Minister.' We felt that we had gone up to a new level, for without that support, our chances would have been slim.

The cost assessment had not been presented at that meeting, because we had not yet had enough data to perform a budget evaluation. Only later, in 1979, did we provide the Ministry of Defense with the assessment that the development would cost 780 million NIS.

However, to all those involved, it was clear that this was only a base figure; meaning that the actual number could only be higher."

One might wonder why the client should care for the development and its cost. Should not the client, who is only interested in new planes, be told only the price he would have to pay for one aircraft or for a given number of units?

Harari: “This is true for civilian projects. If a company wants to develop a new X-ray scanner or a new car, it must indeed bear the risk. Not so in military projects, where the sums invested in development are so high, that the industry cannot afford to take the risk, unless it is guaranteed to have a client for the product. So, the client would give the company a guarantee early on, during the development phase. Today, things are different. The military client still invests in the development, but he expects the company to partake in the risk.”

Harari believes that even the work of the team that performed the feasibility study (a task that, as we said before, lacked organized structure by definition) included many systems engineering elements. This is due to the fact that it had major “systemic” properties, such as the integration of different fields, the need for a broad perspective, the weighing of alternatives, the characterization of the needs of a client (even if it was only a potential client), etc.: “This is the job of a systems engineer. He should be able to handle preliminary planning and system architecture design, to lay out the general lines of the solution – he is the manager of the system architecture. However, we must not forget we are speaking of a time when systems engineering was just beginning to take its first steps. The very term ‘systems engineering’ had not even existed yet. Systems engineering existed mostly in people’s minds, which is exactly the problem it is trying to solve: the goal of systems engineering is to get these ideas out of people’s minds and into the field, to encourage them to act based on structured methodologies that can be tracked, rather than have each person follow his own instincts.”

After the order for was received from the Ministry of Defense, the newly initiated project began to take shape and rely on orderly, systematic activity. But, Harari admits, even then, it was not the carefully organized project one would expect to see from today’s systems engineers: “30 years ago, there was no orderly paperwork and work processes were not systematic, like they are today. Thus, for instance, you would not find an archive with SDR (System Design Review) documents dating back to that time, because such things did not exist, then.”

2.1.2 THE PROJECT

The two teams, technical and political, pushed on in earnest. The feasibility of the project was ripening: “The technical specification was expanding, a more detailed budget plan was taking shape, the Americans agreed to provide us with engine specifications and the Minister of Finance was willing to allocate resources for the project. Even the Prime Minister was involved (Ovadia Harari tells us that Prime Minister Menachem Begin, in his picturesque way of speaking, said: ‘when the IAF commander asks, I stand at attention’), and in February of 1980, the decision was made to launch the project.

Now we had a client – the Ministry of Defense – and an end user – the Air Force – both of whom are very skilled at presenting demands.”

IAI appointed a project directorate, led by Ovadia Harari. The team was comprised of the same group that had performed the feasibility study, joined with other professionals. In the early stages of the project, the team numbered 10–15 members.

The Preliminary Planning Stage

The team began to write requirements documents, which were then given to the company's professional departments. For example, the department of aerodynamics was given a document that detailed the aircraft's configuration requirements.

Harari: "We asked the department's personnel to present us with variations on the given configuration, such as a slightly larger wing or a yoke of a certain size. We also asked them to analyze possible limitations and test them in a wind tunnel (a wind tunnel simulates the flow of air around an aircraft in flight and allows the testers to measure the forces and momentums applied to the aircraft – the authors)."

This was how the matrix management system worked. The project team directed the employees of the professional units by way of the requirements documents. This way, a chain of client–supplier relations was created: just as the Ministry of Defense was the client of the IAI project directorate, the project directorate was the client of the professional units, where dozens of engineers dedicated an ever-increasing amount of time to fulfilling the requirements they had been presented with.

Recruitment for the Lavi Project

The process of recruiting the project's preliminary team was based on the principle of bringing together knowledgeable and experienced people from different professional units. One does not recruit new employees from outside the organization for a project of this scope and complexity. The project's employees must be experienced, skilled, and intimately familiar with the inner workings of IAI, as well as with their colleagues.

Harari: "I consulted my boss and other people in the company, and together we defined whom the project needed; for instance, someone who knows systems, a good radar expert, someone who is well versed in advanced flight control (with the new aircraft, we were entering the electronic flight control category), someone who knows about aircraft structure, someone who specializes in aircraft aerodynamics and so on."

Of course, recruiting experts from the various specialized departments was no easy task. Even knowing the importance of the project, no department manager was happy to give up his best men. As far as they were concerned, our recruitment effort set back the work of their departments. From the outset of the project, the workload of the department managers and their remaining personnel was increased considerably. Moreover, to fill the void, he had to recruit new employees from outside the organization and train them; a process that took time and management resources. In other worlds, the specialized department manager had to cope with the organizational shock suffered by his department, all for someone else's project.

To deal with these constraints, the project administration cooperated with high-ranking executives in IAI; those in charge of the management of the project and the respective specialized departments.

A look at the types of people Harari chose for the project shows that their qualities are what we now know as the qualities that make a good systems engineer.

Harari: "Systems engineers are prominent team members. They are dynamic individuals, involved in many different areas; they do not shy away from anything.

They are open-minded; they ask questions and have a dialogue with you (as a manager). If you want something from them, they don't just go and do it, they ask you what you need it for. They sit with you and examine whether a different solution is also acceptable, they test the extent of leeway you give them. Over the years, I have worked with many such individuals in the company. I had gotten to know them. And when the project was underway, I came to my boss and told him whom I wanted. I wanted this person from Electricity department, that person from the Radar department and a third person from Flight Control department."

On Managing People

With great sincerity, Harari tells us of the way he had managed his team, and the lessons he learned, mostly in relation to his centralized management method.

When asked whether he consulted each expert on questions related to his own field, or generally asked everyone's opinion on everything, he responds: "Today I know that it is better to do all the work together. Not working this way (and many project managers still do not know how to do this right, even today) produces inferior results. People need to be included.

I was a centralist. I did not include them enough. Still, there were those among them who would not let me do what I wanted. Looking back, I now see that I had acted incorrectly."

But why choose this way over others?

Harari: "Today's management approaches encourage sharing. But back then, the manager was perceived as a macho, and his word was law. Managers thought they knew everything. Moreover, at the time, managers were very dominant, and so they found it easier to manage this way. There were very few objections, because managers were respected. Thus, my attitude did not cause any arguments to speak of, because people appreciated me.

This dominance became especially prominent when deadlines began to loom overhead, and the manager was under pressure to quickly move the project forward. In these situations, people needed to be spurred to work harder, which encouraged machismo. But this was not the right way to manage. In time, I learned that good systems engineering is cooperative systems engineering."

That being said, the dilemma of whether or not to share is quite real: if one of the main constraints many projects face is indeed tight schedules, and consulting and sharing take up valuable time, might it not be better to share less and centralize more, if only for practical reasons?

Harari believes that, in these cases, the downsides of a centralized approach outweigh its benefits.

Harari: "At the end of the day, it is not more practical. The sharing approach does take more time (in the short term), but it increases people's sense of responsibility, because they feel involved. If you just order them around, they become small minded. Systems engineering is people-oriented in essence ("people-oriented" is a term taken from a management model that places managers on a scale: at one end, stands a "people-oriented" manager, while at the other stands a "task-oriented" manager – the authors). If you cannot share and seek advice, you have failed as a systems engineer. You must convince your employee that your way is the right way. You have to compromise, otherwise people become small-minded. When you do not let people express themselves, they close up. Even if they have good ideas, they do not express them. They say to themselves: ‘this manager has already made his decision; he doesn’t want to be confused with facts.’ If you make all the decisions yourself, you may save time in the short term, but if you make the wrong decision now because you failed to include other people, and six months from now, that mistake causes a problem, it will be very hard to correct it. Moreover, the correction will take a very long time, because you will have to go back to square one. So, when you look at the bottom line, which approach is more time consuming?”

The Structure of the Project’s Directorate

The centralized management method also dictates the structure of the project’s management. Harari addresses two important lessons he had learned in this context:

The first lesson concerns the fact that Harari effectively filled two positions: that of the project manager and that of the chief systems engineer.

Harari: “The fact that I had to fill both positions was detrimental to the project. I thought I knew everything and believed myself able to work 18 hours a day.

The lesson I learned was that in a project with a budget scope of 10–15 million dollars (and a team larger than 10–15 people), the two positions of project manager and chief systems engineer must be separate. In a project of this magnitude, there needs to be someone whose job entails mostly management – the management tasks take up most of the project manager’s time. If he fills both positions and has to handle the technical issues as chief systems engineer on top of his management responsibilities, processes are delayed or produce mediocre results. He is forced to make decisions quickly and has no time to consider all the aspects and implications. Alternatively, decisions are postponed, which ramps up the costs.

In these, large-scoped projects, a chief systems engineer must be the deputy of the project manager. He must handle the project’s professional aspects like electrical systems, software, or electronic warfare. He should not have to deal with the management aspects, unless they are entwined in the technical work. For example, he should be included in the project manager’s meetings with the client, in order to present the technical aspects.

In smaller projects, one person can fill both positions.”

Discussion:

The dilemma of whether or not to separate the two positions raises a principle question about the interface between systems engineering and management. The defining traits of systems engineering, such as the ability to integrate and coordinate various elements, or the ability to see things from a systemic perspective, can also be found in management. The question, therefore, is: to what extent is the practice of systems engineering also the practice of management, and is the separation between these two fields not artificial?

Harari's words suggest that systems engineering is a management practice based on technological knowledge. Technology, by definition, always entails the integration of subsystems. It follows that if a manger is one who manages organizational systems, then a systems engineer is one who manages technological systems. He, therefore, has to be an engineer by trade, because he has to understand the field he manages. Thus, unlike the professional manager, who is able to move from a management position in one area to a different management position in an entirely different area for "management is management," a systems engineer can only be effective when dealing with his own technological specialization. To conclude, Harari suggests that a system engineer is an engineer with management skills that allow him to perform the necessary technological integration, while using abilities that lie outside his areas of technical expertise (such as budget management).

The second lesson concerns the size of the project team and its effect on the work pattern with the company's professional departments.

Harari: "The Lavi project team increased in size as the project progressed. Eventually, the number of people approached 100. Each system had its own systems engineer, who was in charge of advancing its development and working with the professional departments. There were also systems engineers in charge of the development of subsystems (such as the flight control computer).

This was not the correct approach, because it made the team too dominant. There were so many good people in it that it ended up overshadowing the professional units, which created many disputes. The team dictated the solutions to the units and was too involved in their work. Professional departments do not like this level of interference. It is in their nature to say: 'you have given me the specifications for what you want, now step aside and let me do my job.'

A situation was created, where a powerful group that controlled the money and the client was making the lives of the specialized department teams miserable, causing them to become small-minded. The specialists thought: 'even if I have other ideas, the project administration will never let me express them, let alone try them out.'"

Later, Harari implemented this lesson in other projects he managed and delegated some of the authority to the departments that provided him with their professional services: "Instead of the systems engineer in charge of the navigation system being a member of the project team, he was a member of the professional department. In the next project I managed, which was no smaller in scope than the Lavi project, the project team numbered only 20 members. The systems engineers in charge of developing the aircraft's systems were members of the professional departments. In areas pertaining to the project, they were subjected to me; but they remained within their respective systems and the department manager continued to serve as their direct supervisor. This approach made the department more committed to the project."

To counter our argument that this approach forces the project manager to give up some of his power, Harari says: “This is the right way, so you have to compromise: you give up some of your power, but you get dedication in return. This is how I tie the departments to the project. Had I not done this, I would have had 90 commandoes surrounded by servants – that is no way to work. The right way is to form a small commando force and surround it with people who are committed, and feel that they are half-commando themselves.”

Eventually, after about 2 years of preliminary planning, the concrete requirements for the Lavi plane were finalized, and the configuration and structure of its systems were defined.

Ovadia Harari expands and demonstrates: “By then, we had obviously already decided which engine the aircraft should have. We knew the size and weight of the radar system; we knew what performance to expect from it, how it would interface with the other systems on the plane and how much it would cost. The same was true for the fuel system: we already knew how the fuel tanks would be deployed inside the plane, how the fuel would be transported from place to place, how the tanks would be filled and emptied, how the aircraft would suction fuel even when flying upside-down, what the fuel flow rate would be, and which pumps we had to use to achieve it.”

Costs and Budgeting

The preliminary planning also allow to formulate a more accurate budget framework. Harari had predicted early on that the cost of development would exceed the 780 million NIS mentioned in the preliminary planning stage (this preliminary amount was determined only to represent a starting point, which would allow the team to take on this large, complex mission). Now that the planners had much more data, the specification was much more accurate and allowed them to price each system and subsystem, presenting a better-founded budget estimate.

Budget constraints always stood in the background of the work. Development costs, as well as the price of producing a series of aircrafts, were taken into account. Harari: “It was clear to us that the cost had to be able to compete with the price offered by other sources. Even if our work was more expensive (the price of local production), the difference had to be reasonable. For example, if the current price of a Kfir was 7 million dollars (early eighties dollars, of course), the client would expect the price of the Lavi not to exceed 8 million dollars.”

In time, it turned out that money was indeed important, but not important enough. The knowledge that the project was not limited by a fixed cost, but rather priced using the cost plus method (see above), as was common practice for defense projects during that time, allowed the project’s engineers to give extra weight to technical considerations. This approach was based on the, then correct, assumption that in the end, someone would pay for the product. The team later discovered that while essentially true, that assumption had its limits: when the deviation from the original budget grew out of proportion, the project was eventually discontinued. Harari believes that had the project used fixed pricing, the IAF would have had Lavi aircrafts today.[1]

Harari: “Today, clients require life cycle cost pricing (a method that prevents surprises at the end of the road – the authors). But 30–40 years ago, we did not know what that was; everything was done en route. This approach had a defining impact on the evolution of systems engineering. In the past, defense industries emphasized performance, even if the costs were high. Today, it no longer works like that; budget planning is of fundamental importance.

When we worked on the Lavi project, we did consider the financial aspect. But we kept it in the background, and never gave it much weight, even though I knew that money was a crucial factor. This is a lesson I implemented in the very next project I managed.

Not only should the project manager and his chief systems engineer (in the Lavi Project, Harari filled both positions. For more on this issue, see above – the authors) maintain the balance between the technical and financial needs, but each and every systems engineer has to take the budget issue into account in his work. A systems engineer must have financial, as well as technological training. He must understand that money is a vital parameter. If a systems engineer focuses solely on technology, he will not have the balance required of a good systems engineer. A systems engineer must understand finances and know how to combine technology and money correctly.

Not only is this necessary when considering the aircraft as a whole, it is also a vital element in the design of each and every subsystem. There has to be a balance between technology and money. After all, the systems engineer who oversees the planning of the radar also has to work with a specified budget allocated to the development of that particular system. He has to make decisions within the limitations of the financial constraints. He must make tradeoffs between the level of technology, the budget and the schedule. He must meet the financial goals. Use of the cost-plus method decreases the responsibility of the one performing the project. During those years, the client would ask for a change, and the change would be made. Both the client’s representative and the performing company knew that the costs would be covered. Such things could never happen today.”

We illustrate this principle by providing an example: suppose a client wishes to include an upgraded radar system in the aircraft, without considering the cost of such an upgrade. It is then the duty of any responsible systems engineer to raise the price issue before the client. He cannot be satisfied with saying “this is what the client wants”; checking whether the upgrade is technically possible is not enough. If, after all the factors are considered, it is decided to proceed with the change, the desired activity is repriced.

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[1] According to Menachem Shmul, the chief test pilot of the Lavi aircraft, who also approved the final text for this chapter (following the premature death of Professor Harari), the project was not discontinued due to financial considerations, but because the IDF preferred to receive new planes from the United States. That way, the funds allocated to the project could be assigned to other arms of the IDF.

The Detailed Planning Stage

1982 marked the beginning of the "detailed planning phase" of The Lavi Project. This was the start of the practical work, when the plans that had been devised in the preliminary planning phase were executed and implemented. The detailed planning included numerous experiments that tested the Lavi and all its subsystems. These were lengthy operations. Thus, for instance, if a subsystem failed a test, other solutions needed to be considered before retesting.

About Creativity and the Methodology: During this phase of the project, the distinction between the theoretical systems engineer and the problem solver systems engineer became clearer. Methodological systems engineering stood at the front of the stage. Creativity, which had been so important in the early stages of the project, stepped aside to make room for methodical, carefully organized work.

Harari: "In the early days of the project, during the development stages, a systems engineer has to be creative, because that is when the big mistakes are made – when there are few people and little money. This is the riskiest part of a project. Therefore, people need to be allowed to express their ideas and dedicate a considerable amount of time to the exploration and serious consideration of their suggestions. One must keep an open mind at this point, to avoid getting stuck on just one thought pattern. Later, as the project takes shape, creativity has to be suppressed, so as not to interfere with the mission-oriented approach the project needs at that point – methodicalness and order become paramount.

But even then, one must not be closed to brilliant ideas. This is not simple; it takes a lot of patience. Not all managers are capable of being patient when an employee shows up at their office after a hard day's work of searching for solutions to the various problems that come up, only to discuss something new and creative that had not been included in their work scheme. The decision of at which particular point in time the manager needs to start aiming for a methodical, rather than creative approach is dependent on that manager's character. If he suppresses creativity too soon, he might suffer great losses and end up paying a lot of money for it."

The question of creativity and the timing of its suppression raise the following dilemma: if the detailed planning stage requires a different skill set than the preliminary planning stage, should not some of the team be replaced? Perhaps preliminary planning requires more theoretical, creative systems engineers, while the more advanced stages would benefit from more practical "men of action."

Harari: "Keeping the same people throughout the project is ideal. But in an eight years long project, like the Lavi was – that is unlikely; it is only natural for some people to leave over the length of such a period. In a project that takes two-three years to complete, however, it is best if the people who started the project also finish it. The main reason for this is that when a systems engineer joins a project at an advanced stage, he does not feel committed to the actions of his predecessor. He took no part in the planning, and so it will be relatively easy for him to reject things during implementation. For instance, if a trial fails, he will tend to blame his predecessor. He will find a way to explain why the previously suggested solution was faulty. In contrast, if the one who designed the system also takes part in testing it and something does not work, that man will not be able to sleep at night. He is the one who defined the solution that would meet the client's need, he has nobody else to blame. This man will work day and night to find a solution. He is committed to the project; he identifies with it; the project is his baby."

Managing Changes

In any large project, certainly one as large as the Lavi, which lasted years, it is only natural that every now and then, demands would arise for changes. It stands to reason that sudden demands for change in plans that have taken months, if not years, to form would create quite a fuss.

Harari: "Demands for change arise all the time. When a requirement is made, one can only hope that it will not be for large scale changes. For instance, if the client demands that the flight range be changed from 300 km to 500 km, then he is essentially asking for an entirely different plane. But if he asks for a different radar capability, it is not as fundamental. It is similar to the comparison between adding a drift system to a car and replacing its 2 liter engine with a 2.5 engine with a continuously variable transmission.

With that in mind, it can certainly be said that changes are the silent killers of any project. Any change sets the project back a ways, and if the change is a big one – the setback can equal a year or more."

How does one handle change requirements raised by the client?

Harari: "In a fixed price contract, we examine the implications of the change, and present the bill to the client. The client has to know that the change he wants will cost him another two million NIS, will postpone the application phase by a month and a half, will increase the weight of the plane and decrease its flight range. Then, being aware of all these parameters, he can decide whether to proceed with the change.

A cost-plus contract on the other hand, is an entirely different matter. There, you need not worry about the budget. You are told: 'No problem, give us a bill for the change and you will get your money,' and then the change is implemented. The client is the boss, and you cannot refuse him.

But even then, a good systems engineer would tell his client: 'I want to understand the reasons for the change you want to make. Maybe then I can find a better way to meet your needs.' A good systems engineer would seek to understand the reasoning behind the client's request, and perhaps convince him that his need can be met in a better way than the one he has in mind.

The two teams, the one from the client's side and the one from the project's administration, sit down and discuss the issue together. Then the project teams study and analyze the need, formulate a response (in the professional jargon this task is referred to as QFD – Quality Function Deployment) and present it to the client. At the end of this process, a plan for the implementation of the change is devised.

This is why one of the most important qualities a systems engineer can have is learning ability. A systems engineer needs to be able to learn, to expand his mind, even at the age of 45. For example, the client raises a demand for an electric flight control system. You cannot tell him: ‘no, I will revert to a mechanic flight control system, because that is what we know.’ You open up the books, you take some courses, and you begin to understand radar systems.”

Either way, to minimize the need for changes, one must invest a considerable amount of time in detailed planning during the project’s early stages.

Harari: “One of the systems engineer’s most important duties is to receive the client’s requirements, carefully analyze them and make sure they are all met. This needs to be done as early on as possible, at the very beginning of the project.

An obvious principle states that the further along the project is when changes are implemented, the more costly those changes become. A large part of all project glitches occurs due to the project managers’ failure to really understand the needs of their clients, and as a result, failing to provide them with a satisfactory solution.

This is exactly why good systems engineering is so important in the early stages of a project. A project stands or falls on its preliminary planning. The problem is that, even today, many people do not know enough about systems engineering and project management, and instead focus on the money and try to speed the process along. These are not just the project managers and their superiors, but the client’s own representatives, who say: ‘Trim it down, time’s a wasting, move it along.’ And on his part, the project manager finds it very difficult to postpone the performance of a certain step towards the accomplishment of his task, when it also means postponing the arrival of a ten million dollar payment.”

Harari distinguishes between two types of change: “One type of change is the kind that depends on the management of a project, who failed to understand the client’s requirements. There were several such incidents in the eighties, when project managers thought they had understood the requirements, only to discover later that they had not, and so were forced to turn back. The client made no new requirements; he only wanted to get what they had agreed on in the first place. For example, say he wanted the aircraft to have a lighting quality that allowed it to fly by starlight, like the Kfir; then suddenly it turned out it was not enough to meet the needs of the Lavi fighter, and changes had to be made. This was a methodological problem that no longer exists in today’s systems engineering. Today’s methodology clearly defines each requirement and how it should be met, demanding that the solution be presented now, rather than later.

The second type of change is the kind initiated by the client. For instance, SA-17 missiles have entered into play and the client wants the aircraft to be able to take them on. What should we do? If the project were still in its early stages, the change could be considered. But if the requirement came up during detailed planning, it would be unacceptable, because the cost would be too high.”

Today’s systems engineering offers a solution that minimizes the damage of such changes by creating built-in flexibility in the aircraft’s systems. This approach was used in the Lavi project as well.

Harari: “We built a potential for expansion into the planes, allowing their capabilities to be upgraded. Today, this is considered common practice. Blocks of potential change are constructed, using forward thinking. For example, if the client asks for a 50% increase in the aircraft’s computing capability, he does not expect to see the changes in the very first plane produced.”

2.1.3 THE END OF THE PROJECT AND FURTHER INSIGHTS

The Lavi Project was never completed, but it came fairly close. In late 1986, the first Lavi prototype flew across the skies of Israel, but the question of the project’s discontinuation was being debated months prior to that flight.

In the end, budget considerations (some of which came as a result of the use of the cost-plus method, which created a deep budget hole) alongside internal and external politics (the internal considerations had to do with the upcoming elections and power struggles between the Ministry of Defense, the IDF, and the Air Force, while the external ones were related to Israel’s reciprocal relations with the US government) tipped the scales. IAI was preparing to terminate thousands of employees.

Harari was appointed another position, where he had to handle the management of another large project. This time around, he came prepared as a much more experienced and mature project manager and systems engineer. Lessons he had learned from his management of the Lavi project were implemented in the new project right away. Some of these lessons have been discussed here. Next are some additional insights Harari has to offer on systems engineering.

The Essence and Evolution of the Systems Engineer Profession

- A systems engineer is, first and foremost, a technical man, who has to deal with lateral, technical management issues. The professional-technical aspect has always existed in the industry (systems engineering being a field with strong ties to the industry). The new aspects systems engineering has brought with it are aspects of lateral management, because today’s systems are more complex and more convoluted. Projects are also getting larger (and subsequently more expensive and more complex) and demand a more methodical, hierarchical approach.
- The work of a systems engineer can be divided into three areas: management related, professional, and technical.

  Some examples of each area include:
  1. Management related – a functional disassembly of the project: constructing the schedule, formulating the budget, and devising a configuration control plan.
  2. Professional – lateral: integrating the safety plan, maintenance plan, testing plan, risk mitigating plan, and quality control plan. Overseeing the quality of the entire aircraft.

3. Professional – technical: authoring requirements and compliance documents, designing system architecture, making engineering trade-offs, raising test requirements, and devising integrated tests.

- Developments in R&D have increased the demand for systems engineers. Development systems need the multidisciplinary connectivity that characterizes systems engineering. As a result, systems engineering has mostly evolved in industries where projects are large and complex: defense, aviation, space, software, energy (nuclear), and medical systems. Developments in systems engineering received a substantial boost in the 1990s, as a result of the accelerated development of the software field. In hi-tech, the development component is very dominant. Other industries are including more and more software in their projects as well.

The Required Skills

- A systems engineer needs to know how to handle a range of areas. For instance, in aeronautics, he needs to have knowledge of the structure of a plane, computers, and radars.
- A systems engineer is a methodological person. He has a method and the tools to use it. He must adopt process-oriented thinking. A systems engineer must finish the requirements document before he begins planning.
- A systems engineer must have a basic grasp of all the areas the project concerns itself with, because he needs to be able to ask the right questions. If I sit in a meeting at the power company, barring common sense questions, I will not know what to ask. In a meeting concerning the development of an aircraft, however, I will have all the right questions.

The Required Competences

- A systems engineer has to be a multidisciplinary individual, a man of many talents, able to talk to the experts in a clear, simple language.
- Leadership and teamwork are more important for a systems engineer than professional leadership. Soft qualities are vital; otherwise, people simply will not follow him. These qualities are needed to motivate people and handle crisis situations with them. A systems engineer needs to be a people person – a sociopath can never be a systems engineer.

- A successful systems engineer is an integrator who knows how to combine engineering with management abilities.
- A systems engineer must see the whole picture and use common sense to filter out the less important details; otherwise, the endless dive into the small details will disrupt his work processes.
- A systems engineer has to be able to quickly jump from subject to subject.