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Industrial warehouse construction

Context

We are tasked with managing the project for building a warehouse of area 3000 m^2. Warehouses of such scale are used to store large quantities of inventory, usually for commercial purposes. Modern warehouses aren't just big empty buildings with shelves for storage of inventory, they are a tightly controlled environment that can accommodate a wide range of inventory ranging from metal to food to chemicals. Such a controlled environment helps preserve their original state before they can be used in any process and is hence an import part of the whole industry. As the old adage goes, 'you build something, now you have to store it somewhere or else it will be as if you never built it'. As the project manager, we need to initiate the project by formulating a detailed strategic document to lay out a guideline for the high level goals of the project.

Major Tasks

The main goal of the project is to build a 3000 m^2 warehouse, which means it must have an area wise storage capacity of 3000 m^2. In general, we need to manage the all engineering aspects involved in the construction of the project. The tasks involved are detailed below.

Structural requirements for such buildings generally stipulate that the building must have deeper foundations to withstand the downward forces exerted by stored inventory for handling uneven loads contained within the warehouse and vehicle entry points must have additional strength to balance withstand concentrated loads, for example, a truck unloading dense materials such as iron onto the warehouse exerts more pressure in the foundations due to iron's higher density. Since only vertical loads are stored in warehouses, supporting pillars must be designed to support the roof load and to efficiently distribute loads of the storage shelves into the ground through the foundation.

Mechanical requirements for such buildings include HVAC installation to make sure that stored inventory remains in proper conditions. These can be designed to suit the needs of the warehouse according to the intended inventory. For example, heat from parts of the building that need to be kept cool can be channelled into parts that are intended to be a warm. But that is simply not enough for a modern day warehouse.

Modern-day warehouses are large DCSs (Distributed Control System), filled with a multitude of sensors monitoring the status of all parts of a warehouse and adjusting their control mechanisms accordingly. The instrumentation system should contain a bare minimum of humidity & temperature sensors all over the building, linking back to the DCS which contains HVAC control, Power flow control and overall supervisory control of the building. The electrical system should contain backup generators, voltage stabilizers, inverters, AVR (Automatic Voltage Regulators) & VAR (Volt-Ampere Reactive) compensators to improve the overall power quality in the warehouse. The building must be equipped with large hoisting cranes for moving around heavy loads and must contain elevator & conveyor belt systems to move inventory to the higher parts of the storage shelves. A fleet of forklifts must be bought as well to help personnel move things around.

Manager Profile & Task Designation

We are a team of 3 professionals with a collectively diverse set of backgrounds. Introducing first, our first team member Mr. Raju Khatri.

Mr. Khatri has a background in engineering and has experience with running business operations. He has been involved in most tasks mechanical such as design, analysis, sourcing and installation of heat exchanging systems and by extension HVAC systems in general. He has experience with designing instrumentation and control architecture for industrial settings. He also has knowledge of budgeting and some accounting. His skill-set spans electrical, mechanical and managerial tasks. He is an efficient leader who can identify gaps in any project and allocate resources towards those tasks to make sure that all subtasks are on par with the set deadlines

Dr. Tania Rogers has a background in structural mechanics and project management and holds a doctorate in the former. Her portfolio states her involvement with building a plethora of bridges and large industrial complexes. She has specialised knowledge of materials science, soil mechanics, hydrology and structural analysis. With her expertise and credibility, she brings the ability of ease of direction of personnel as she has a clear idea of all the moving parts that go into building of any civil structure. She has a good understanding from the supply chain logistics in the structural industry to having good contacts with a wide range of specialists from cross-disciplinary fields.

Ms. Audrey Ramos is an electrical engineer by practice and has been in the industry for 20 years. She has expertise in development of large power systems and has been involved in and lead the design and commissioning of both on-grid and off-grid energy projects. She has skill with handling every type of power systems related projects which include power quality improvement design, analysis of power supply defects in the systems and overall reliability & efficiency of installed systems. She is an excellent manager who can direct people effectively. The biggest skill besides her expertise, that she brings to the table is her expertise with handling of licensing deals revolving around the project. She has developed an effective systems and network of people to handle such deals with reduced effort.

On the basis of their expertise, each project manager can be assigned a large part of the project. Dr. Rogers, with her expertise is given the responsibility of end-to-end construction of the whole warehouse. She will be responsible for setting the construction deadlines and preparing the preliminary budgeting fact sheets in order to help the other project managers plan out their timelines for timely procurement and commissioning of their systems. Since Dr. Rogers is herself a contractor, she won't have any issues with hiring as she already has a set team who knows how to achieve deadlines with the highest quality of work. She will also be responsible for coordinating with the other project managers as the structural work of the building needs not be complete before the other teams can start working on the mechanical and electrical systems

Ms. Ramos's work begins even before that structural team starts i.e. she will be responsible for making arrangements for power routing before construction begins after which her team waits for Dr. Rogers. After a green light from Dr. Rogers and her team, Ms. Ramos will begin her work on developing the power system for the warehouse. Her team will also be responsible for building an off-grid power source. She will also be simultaneously handling the legalities regarding the licensing & purchase of land and other technology and will be the main representative of the project from the government's perspective.

Concurrently, Mr. Khatri's team will begin working on the mechanical systems at the same time as Ms. Ramos and will coordinate his efforts and construction & procurement timelines to match up with the structural team so as to make sure that the mechanical systems of the warehouse are completed within a week of the structural team's departure. Mr. Khatri will also coordinate with his counterparts to finish the project concurrently.

To ease communication & scope out requirements mid-way and re-assess the budget through the process, all the project managers shall have a meeting with stakeholders after completion of initial structural tasks of the project, i.e. before the electrical and mechanical systems are installed.

Project Costs & Timeline

Akura, an australian consultant states on it's website that it costs anywhere from $1500-$2000 per sq. m. for complete design and construction of warehouse buildings. While Koste suggests that multi-storeyed warehouses cost $1680 per sq. m. in Perth to build. Projecting our estimates according to this, our industrial warehouse complex can cost anywhere from $4.5 million - $6 million if Akura consultants are commissioned the project. With the our expertise at hand, we can estimate these costs can be significantly reduced as larger-sized warehouses have reduced material prices from raw material vendors as well as a completely streamlined supply chain thanks to Ms. Ramos' expertise can reduce logistic overheads significantly. The exact figure for this estimate can be declared only after all 3 teams perform their detailed economic analyses. For a working estimate, we need to resort to available data on the major parts of the project in order to obtain a reasonable initial budget plan. For this we have referred to data available through various sources. After some general research, it was found that the major costs in the project can be categorized according to soft costs, hard costs, long-term costs, financing costs and concrete foundation cost, as mentioned in this website, which is of course not a final estimate. Listing them out in a table:

Particular	Cost	Total
Variable Costs	Includes consulting, design and engineering costs. Hard to come up with exact figures. Estimate $200 per hour per consultant (2)	~$387,200
Fixed Costs	Steel - $524 per ton (~30 tonnes required) Manpower Costs - $75/hour/person (10) Other materials - $100 per ton of steel	~$15,000 ~$1,089,000 ~$3,000
Concrete Foundation Costs	$64.58 /m^2 i.e. ~$200,000 for 3000 m^2	$200,000
Long-term Costs	Electric Utility Costs - $0.18/kWh (100 MWh)	~$18,000
Overall Cost Estimate	-	~$1,712,200

Table 1: Tentative costs- Daily costs times 121 days (Real costs may vary)

Data on warehouse construction from World Bank suggests that in Australia in 2019, it took on average, 121 days to build a warehouse, which is why we have used the number above. Energy demand per hour is estimated to be around 34 kWh. On the time required to complete construction of the warehouse, the company XLStructural provides estimates for a commercial building of around 2000-3000 m^2 with 300-400m^2 office space. The construction timeline is broken down as:

Phase			Duration (in weeks)
Planning and Design	Conceptual Design		2-8
	Resource Consent		2-48
	Detailed Design Report		8-20
	Design Completion		2-3
	Building Consent		6-12
Construction	Site Preparation		2-10
	Floor & Foundation		6-10
	Warehouse	Constructable	9-12
		Fit-out	4-6
Overall			**37-135**

Table 2: Duration estimates by XLStructural

Since the information provided is for any commercial building and since design of a warehouse doesn't need to be designed much, we can evade the 22-91 weeks that might be spent on planning and design. Our teams are confident that we can finish the above in the following duration revised by us:

Phase			Duration (in weeks)
Planning and Design (Concurrent)	Conceptual Design		1
	Resource Consent		1
	Detailed Design Report		2-3
	Design Completion		0
	Building Consent		1
Construction	Site Preparation		2-4
	Floor & Foundation		6-8
	Warehouse	Constructable	9-12
Overall			**19-27**

Table 3: Our modified estimates (Real duration may vary)

Quantitative Estimation

Using the data with standard statistical measures can give us a probabilistic estimate of the costs and duration. Assuming normal distribution for all data, we can decide on tentative mean and 1-standard deviation values to obtain the normal distribution curve for each of the individual costs and durations and then use the z-score method to normalize them and draw comparisons.

Phase			Duration (weeks)	Mean (μ)	1-Std. Dev. (1σ)
Planning and Design (Concurrent)	Conceptual Design		1	1	0
	Resource Consent		1	1	0
	Detailed Design Report		2-3	2.5	0.5
	Design Completion		0	0	0
	Building Consent		1	1	0
Construction	Site Preparation		2-4	3	1
	Floor & Foundation		6-8	7	1
	Warehouse	Constructable	9-12	10.5	1.5
Overall			**19-27**		

Table 4: Mean and standard deviation table for work duration

For costs, assuming one standard deviation values are 10% away from the mean

Particular	Total	Mean (μ)	1-SD (1σ)
Variable Costs	~$387,200	387200	38720
Fixed Costs	~$15,000 ~$1,089,000 ~$3,000	15000 1089000 3000	1500 108900 300
Concrete Foundation Costs	$200,000	200000	20000
Long-term Costs	~$18,000	18000	1800
Overall Cost Estimate	~$1,712,200	1712200	171220

Table 5: Mean and standard deviation table for major costs

The formula for normal distribution is given as

$$\frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(x-\frac{\mu}{\sigma}\right)^2}$$

The data points were used in this formula to obtain the following plots

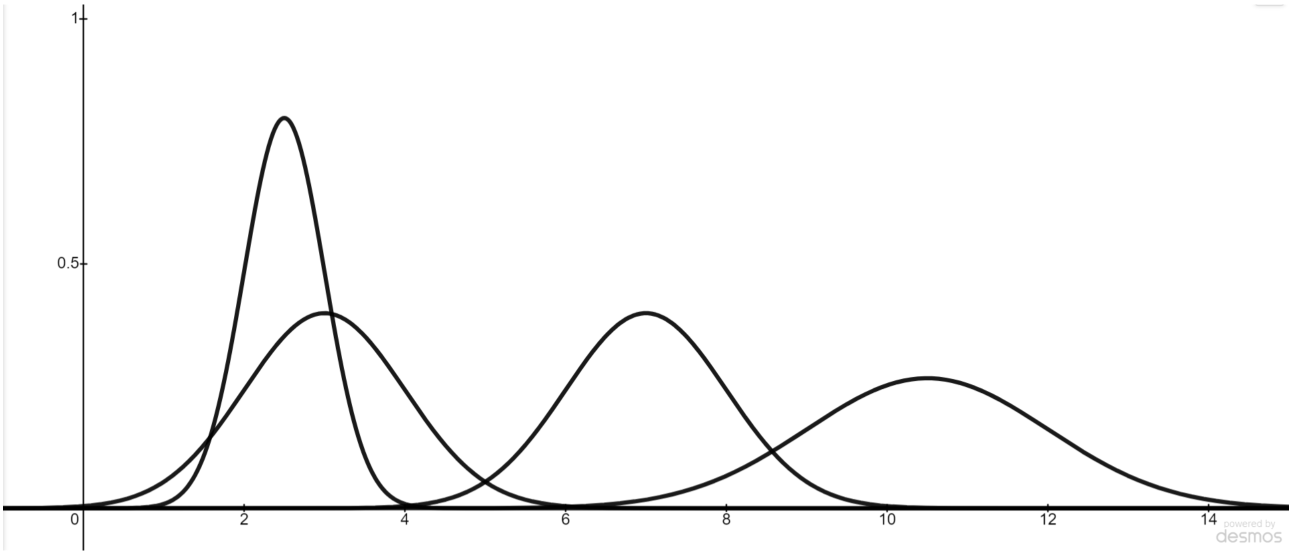

Figure 1: Work duration components' distributions plotted in Desmos

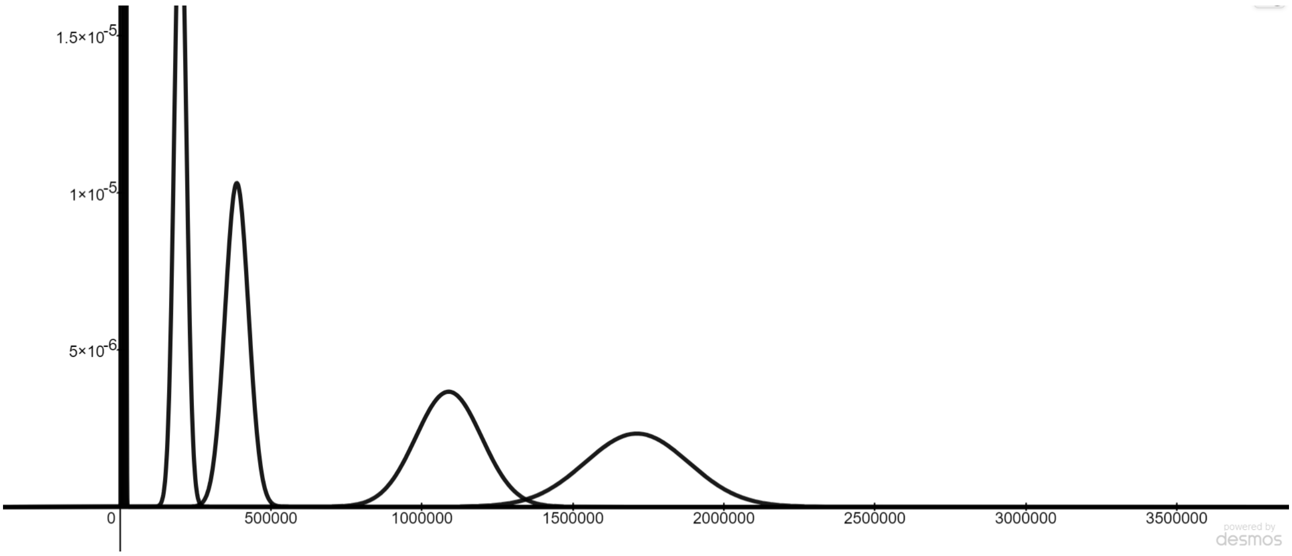

Figure 2: Major costs components' distributions plotted in Desmos

The plots show us how price or duration of each parameter are distributed. For 90% confidence estimates of each component, we can calculate confidence intervals for each of these distributions and sum them all up. A 90% confidence interval is given by the $\pm 1.644854\sigma$ range. Calculating these can help us find the overall 90% confidence interval for both the price and duration of work.

Plotting all of these into separate tables

Mean (μ)	1-Std. Dev. (1σ)	90% Confidence Interval	
		Lower Limit	Upper Limit
1	0	1	1
1	0	1	1
2.5	0.5	1.68	3.32
0	0	0	0
1	0	1	1
3	1	1.36	4.64
7	1	5.36	8.64
10.5	1.5	8.03	12.97
Overall 90% Confidence Interval		19.43	32.57

Table 6: Final 90% Confidence Intervals for Work Duration

Mean (μ)	1-Std. Dev. (1σ)	90% Confidence Interval	
		Lower Limit	Upper Limit
387200	38720	323511	450889
15000	1500	12533	17467
1089000	108900	909875	1268125
3000	300	2507	3493
200000	20000	167103	232897
18000	1800	15039	20961
Overall 90% Confidence Interval		1430568	1993832

Table 7: Final 90% Confidence Intervals for Major Costs

Therefore we statistically expect with 90% confidence that our work will be completed

in **19.43 to 32.57 weeks** with a **$1.43 to $1.99 million USD budget**

Operational Risk Mitigation

The operational risks that come along with construction projects can be broadly classified according to their sources according to [4].

Management quality	- Decision error & insufficient data for making concrete decisions
System risks	- Obsolete, insufficient & unreliable technology use
Human factor	- Personnel incompetence, operational error & fraudulence
Process	- Insufficient process control & delivery risk
Force majeure	- Natural calamities, terrorism, etc.

A more detailed list along with quantitative measures in the form of a risk significance index is provided in [3]. The index for example gives Inadequate contractor experience an index value of 32.80 while accidents during the construction an index value of 29.00. This must make logical sense that the former can cause a lot of the latter, which is why it has a higher index. Therefore, these classifications can be directly used to evaluate the level of operational risks of each of the risk factors. The specific risk factors important to us are:

1. Lack of communication
2. Changes is material types and specifications during the construction
3. Soil condition effects
4. Weather
5. Delay in permits from government
6. Land handover delays
7. Repair tasks due to construction errors
8. Work delays
9. Delays in subcontractor
10. Difference in design documents
11. Longer decision making duration
12. Construction accidents
13. Force Majeure

These risks can be mitigated by setting up a temporary risk-mitigation sub-committee which can constantly monitor & discuss each group's scope of work. These can be run by basing their discussions on the following protocols:

1. Thorough soil risk assessment before site preparation
2. Scheduled legal updates from the legal team
3. Safety updates meetings with the personnel lead
4. Week-ahead planning for unfavourable weather or state-predicted calamities
5. Constant communication between the 3 project managers
6. One-on-one personnel training before operation of machinery
7. Deals with multiple sub-contractors such that incompetency by one will lead to complete takeover by another. Practically this should happen immediately after the site preparation process.

Land Acquisition

There are a number of factors to keep in mind for the purchase of land. The location of our site plays a big role in the shift of bargaining power between us, the buyers and landowners, the sellers. Firstly, a coverage radius must be decided which denotes our area of service. Then the site location must be determined such that the economic costs associated with moving inventory in and out of the warehouse is not an issue for potential customers in the nearest industrial areas. This is decided by factors such as road access and typical traffic times. Then a list of feasible locations must be decided on. This is the point where the negotiation strategy comes into play. For a higher bargaining power, we must bid the owner of a piece of land that has a very low commercial value within the next decade. What we're doing here is increasing the municipality's BATNA (Best Alternative to Negotiated Agreement) while simultaneously reducing ours. This shift in the bargaining power due to our initial analysis plays the most crucial role in making sure we get the best deal. After this we must ask ourselves the 6 important questions and answer each one.

1. What is the overall goal in the negotiation?

   Getting the best deal for a piece of land that is an economically feasible site for our warehouse i.e. a good distance away from the commercial area.

2. What issues are most important in reaching the goal?

   Price of land & economic feasibility of moving inventory in and out of the land.

3. What is our BATNA?

   Cheaper lands in the outskirts of the commercial area that have municipal incentives, are economically feasible to operate and have better soil quality.

4. What are our reservation prices?

   Our reservation prices is the price that gives a break-even point within 2 years of operation of the warehouse. Calculated by performing break-even analysis.

5. What is the most likely price?

   A price that allows us to reach the break-even point faster despite the higher upfront costs of acquiring the land and constructing the warehouse.

6. What is our stretch goal?

   Our stretch goals are set at a price that allows us to reach break-even within 20 months of start of operation.

Based on this brief analysis we can summarise our strategy as:

- Assess economic feasibility of multiple sites and shortlist
- Negotiate the land with highest soil quality & normal operational costs first without finalizing the deal
- Negotiate the land with high soil quality but lower operational costs (nearer to the commercial area) and present previous negotiation as BATNA
- Finalize the best offer

Decision Tree Analysis

Post-negotiation land purchase options

Land-A for $200K

Land-B for $160K with a 20% chance of extra administrative costs of $50K

Land-C for $140K with a 50% chance of constructing an $80K road

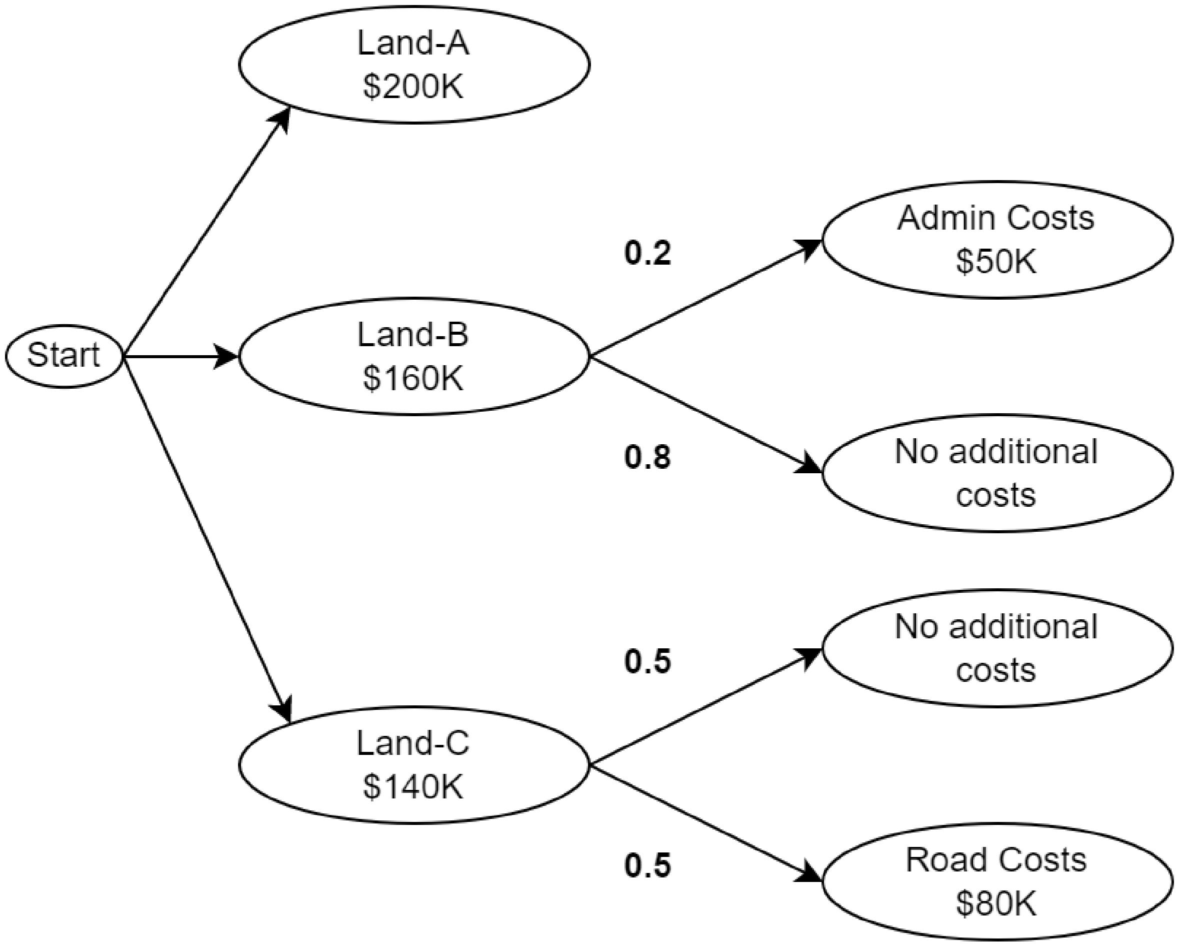

Figure 3: Decision tree for the land purchase options made using Lucidchart

We can calculate the probable prices for each piece of land now

Land-A's BATNA is $200K

Land-B's BATNA is $138K

Land-C's BATNA is $110K

Therefore our best alternative is Land-C with a BATNA of $110K. While this decision can't be independently taken just through the decision tree. We can further analyse that max. price for Land-B is $210K with a 80% chance that the price will remain $160K. But max. price for Land-C is $220K with a 50% chance that the price will remain $140K. Out of the two, Land-C carries far more risk Land-B seems to be a better proposition with regards to risk. Therefore **Land-B is recommended** for the site.

Improving irregular sleeping habits using DMAIC

Define

Irregular sleeping pattern is the root culprit for a large number of bad habits which present themselves throughout the day which are actually actually cascading effects of bad sleep. Bad sleep correlates to a drop in metabolic capabilities, cognition and physical health itself. A good night of sleep leaves you rejuvenated, feeling energetic throughout the day. After a full 7-9 hours of night of sleep, even the afternoon drop in energy isn't enough to generally make people feel sleepy. But getting a good night of sleep isn't as easy in the world we live in. Loved ones may reside in another time zone which may make us stay up later than we intend to. Remote jobs may demand a person in one time zone work according to another in order to coordinate with their team better. This, in addition to habits of browsing through social media with the finger swipe action we know all too well as we go to sleep extends our waking hours unnaturally to more than 16 hours. But obligations of the next day force us to wake up before getting a full night of sleep which makes us more sleepy in the afternoon and the cycle repeats. These factors along wi th a plethora of factors may allow one to not get enough sleep and not feel well rested. But this is not completely random. There is a certain process or protocol to follow if to get a good night's sleep, made known to the general public most prominently by Walker [1] & Huberman [2].

Measure

Measuring the 'up-time' of people through measurements of Adenosine (a neurotransmitter which characterizes 'sleep pressure') levels can help determine whether they're sleeping regularly or irregularly. An irregular sleeper will almost always easily exceed their healthy 'up-time' which is generally around 16 hours. This is a sign that the person hasn't slept well the previous day, having not cleared all the Adenosine in their brain. They need some more hours of sleep but during the morning, when the circadian rhythm (which relates to alertness) is in its rising stages, the alertness level overpowers the built-up Adenosine until there is an afternoon dip in the energy due to the alertness levels plateauing for a while, commonly known by many as the 'afternoon slump'. It is during this time that people who haven't had enough sleep fall asleep more easily than others. If they sleep for 2 sleep cycles which is approx. 3 hours, the people will have rejuvenated due to the Adenosine disposal, but this disposal makes it such that the Adenosine will not accumulate enough for them to fall asleep in their regular sleep period. For example, someone waking up at 6 a.m. after not sleeping well, might fall asleep around 10 p.m. in the evening. But if they sleep for 3 hours, that duration can get stretched beyond 10 p.m. which repeats the cycle again because they might have obligations to attend to at 6 a.m. So does this mean that once we don't sleep well, our chances of having a normal routine is nil forever? Obviously not, because sleep is a highly non-linear process.

Analyze

A huge factor in clearing away Adenosine is played by sleep. But beyond sleep, energy from photons i.e. light energy, especially from the sun when it is at low solar angles in the morning can help clear away residue Adenosine, making a person feel rejuvenated. After this, in the evening when the sun is again at a low solar angle this time sets a reference point in the brain for initiating its inner sleep protocols. This is triggered by the red wavelengths of light during the evening, compared to energizing blue wavelengths during the morning. Another mechanism in play is the amount of light to which a person is exposed to during the night. Dimmer lights means lesser disturbance to sleep.

Improve

The battle of feeling energetic starts in the morning before. Utilizing the mechanisms above, we can form a set of behavioral protocols to follow which allow us to reset our sleeping times. The habit of going outdoors once awake is one of the mechanisms people can utilize to set their waking times. This must be done within 3-4 hours of our body's temperature minimum, which is generally around 4 a.m. [2]. Viewing the sunset in the evening as a form of recreation. Also relaxes eye muscles. Then during the evening, one must have on very dim lights such that they don't have a hard time moving around. This initiates a healthy trigger of the sleep hormone melatonin which induces sleep and we can fall asleep faster and correct the routine of bad sleeping habits. This must be repeated daily to maintain the habit properly.

Control

To make sure that these habits stick properly, doing this for a number of consecutive days is a must. To support the habits metabolically, good eating habits must be formed by eating several well timed nutritious meals throughout the day. Another way to support this habit is to make a habit of integrating evening breaks with watching sunsets. This allows one to take a break from the work they're doing while simultaneously getting ready to fall asleep. Another behaviour that is complimentary to sleeping well is not looking at smartphone screens a few hours before bed time in order to not suppress melatonin production. These sets of controls can help foster these new sleeping habits in order to sleep well and reap the benefits of being healthy and feeling energetic.

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