Improving Australian ski resort surface lifts with a focus on efficiency and inclusiveness via Systems Engineering Approach

ENGN2225 Individual Research Portfolio

Executive Summary:

An alternative ski lifting technology, termed the ‘E.S.S-bar’ (Efficient, Safe, Snowboarder friendly) has been designed via a systems engineering approach. Such a design is a modification of the existing T-bar surface lift and it was found that the E.S.S-bar met the performance requirements of safety, durability, adaptability, speed and cost much better than other surface lifting technologies.

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Four subsystems within the surface lift system; control, power, communication and lifting device systems, were finalised and their inputs and outputs both within eachother and the exogenous system considerations were mapped. It became more evident at this stage that the physical lifting device subsystem was largely independent of other subsystems.

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An analysis of possible construction construction materials for the E.S.S-bar was conducted. From this, it was decided that the main 'E.S.S' modified section would be constructed from polyurethane and an adhesive surface would be constructed from chloroprene.

Testing procedures are described for some of the main design attributes, as ascertained from the HoQ. The E.S.S-bar was verified as the best design solution and a method of using social media to communicate the device is illustrated.

1.0 Introduction

The Australian ski season is characterised by inconsistent snow falls and, compared to Northern hemisphere resorts, a comparatively short season span (June to mid-September depending on snow coverage). Therefore during peak operating period's local resorts are usually over-crowded. This can mean during these periods, patrons often spend a majority of their time waiting in lift lines rather than skiing or snowboarding on the mountain. Additionally, the main surface lifts currently in operation in Australian resorts, T-bars, J-bars and rope tows (illustrated in figure 1), were initially designed to be used by skiers alone (Comparison, 2015). This means that snowboarders, which presently make up a large portion of mountain users, have had to adapt. These adaptations have often come through sacrificing user comfort as when snowboarders operate T-bars, all of the applied loading is centred on the users' inner thigh. This is shown below in figure 1a and can be very uncomfortable and unstable for the user. The term 'surface lift' (figure 2) will be defined henceforth as any ski or snowboard lift which transports users to an area of higher elevation by a means in which the users' ski or snowboard remains in contact with the snow surface.

Figure 1: Typical Australia ski resort surface lift types [A] A T-bar (Tan, 2012) [B] A rope tow (Anon., 2012) [C] a J-bar lift (Frank, 2013)

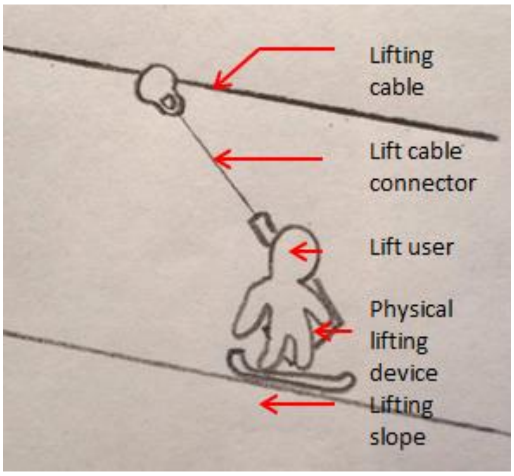

Figure 2: basic surface lift components

2.0 Improving Quality through whole of system design

A *front end loading* design approach was adopted within this project, whereby a great emphasis was placed on the initial development process. This approach is often adopted in systems engineering projects due to its effect in minimising the incurred costs, both time and money based (Stasinopoulos, et al., 2008).

As part of this design process, conceptual designs were examined immediately after the relationships between the design attributes and requirements became apparent (table 3 HoQ) and surface level analytical testing was conducted thereafter. This allowed a design structure to be finalised (figure 3) and a subsequent materials analysis to be undertaken. The final material chosen for the modified T-bar surface lift design was polyurethane. Although this material was chosen primarily because modern day T-bar's are constructed from this polymer- as ascertained through a Google Patent Search (Macfarlane, 1987)- considering the designs' end of life stages further validated the choice of polyurethane. Polyurethane is demonstrated to be readily recyclable and reusable through a variety of both chemical and physical recycling processes. The most environmentally friendly method currently available to reuse polyurethane is a physical recycling process whereby the material is crushed and re-moulded. This reuse consideration has the advantage of being cheap and efficient (Yang, et al., 2012).

3.0 The Design Solution

Through the use of a systems engineering approach, the design solution generated was a modified T-bar design known as the 'E.S.S-bar' (figure 3). The E.S.S-bar could work as an attachment to existing T-bars in Australian ski resorts, and was designed with a direct focus on improving the efficiency and inclusiveness of surface lifts for snowboarders and skiers alike. Further justification for the design solution is given within this report.

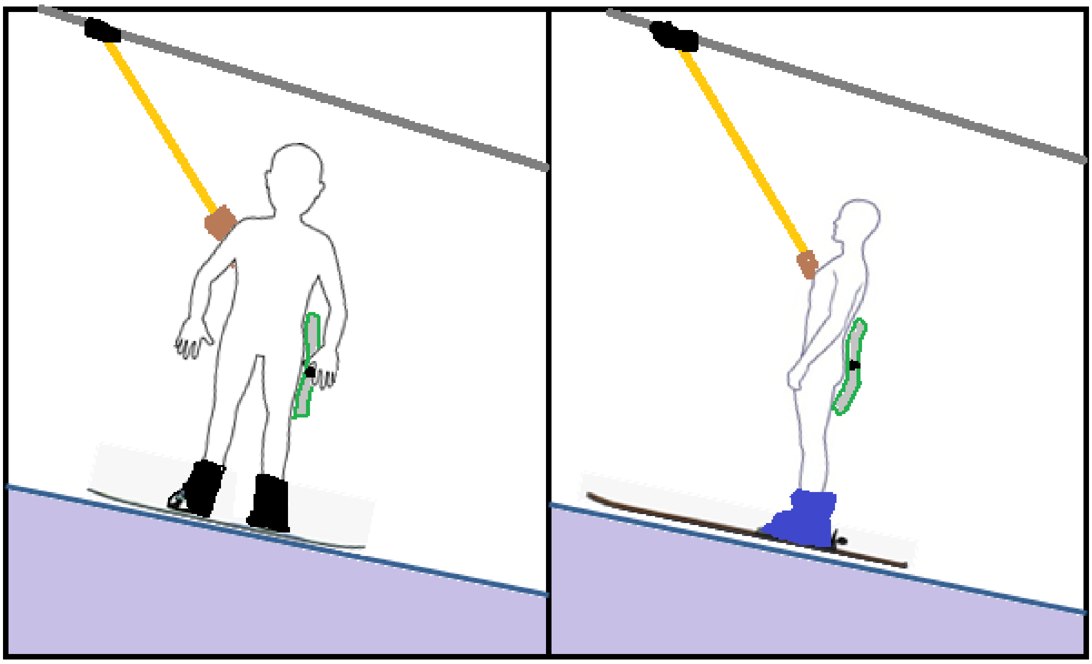

Figure 3: (left) snowboarder use of the E.S.S-bar, (right) skier use of the E.S.S bar

4.0 System Scoping

In order to improve the efficiency and inclusiveness of surface ski lifts in Australian resorts, the following performance requirements will be assessed; safety, speed, durability, cost and adaptability. These were chosen as they implicitly stem from the problem statement with the performance requirements of safety, adaptability and cost falling under the general heading of ‘inclusiveness’ whilst speed and durability fall under ‘efficiency.’ These very general performance requirements can be further specified into design requirements, shown in table 1 below. Each of the design requirements is then briefly assessed, where applicable, against the three present day surface lift designs in Australian resorts detailed in figure 1. This will allow the solution space of design alternatives to become directly apparent.

Table 1: Translating performance requirements into design requirements with additional design evaluation

Legend: 0 = non-compliance, 1 = partial compliance, 3 = full compliance, 9 = exceeds compliance, - = could not be determined

Performance Requirement	ID	Design Requirement	T-Bar (figure 1a)	Rope Tow (figure 1b)	J-Bar (figure 1c)
Safe operation	DR01-01	Correct operating speed	3	3	3
	DR01-02	Reasonable operating height	3	1	3
	DR01-03	Lift fastening mechanism	3	1	3
	DR01-04	Lifting mechanism	1	1	3
	DR01-05	Force on user	1	1	3
Speed	DR02-01	Linear speed of lifting	3	1	3
Durability	DR03-01	Available spare parts	-	-	-
	DR03-02	Materials used in manufacturing	-	-	-
	DR03-03	Location of lift relative to other natural features	-	-	-
Cost	DR04-01	Materials used	-	-	-
	DR04-02	Relative lifting capacity	3	1	1
	DR04-03	Ongoing costs	-	-	-
Adaptability	DR05-01	Transport multiple objects	3	0	1
	DR05-02	Operation in variable weather conditions	-	-	-
	DR05-03	Easily adjustable controls	-	-	-
	DR05-04	Ease of operation and use	1	0	1
Total			24	1	24

From this surface level existing design evaluation, it is clear that both the J-Bar and T-Bar demonstrate a much greater compliance with the relevant design requirements. Throughout this surface level evaluation, scores were given based on user knowledge of each of these surface lift types. There is a definitive need for improvement, in regards to many of the design requirements, particularly the ‘ease of operation and use’ and the ‘lifting mechanism.’

These two requirements are closely related, as verified by the House of Quality (HoQ) in table 3.

When clearly defining the systems engineering problem at hand, it is paramount to set a scope for the task. A good method of setting a system boundary is grouping all aspects of the system into endogenous, exogenous and excluded categories. These represent internal system factors, external system factors and irrelevant system factors which lie outside of the system boundary respectively (table 2). Following the problem scoping table, a typical use case for a surface lift is shown.

Table 2: Problem Scoping Table

Endogenous (inside the system boundary)	**Exogenous (likely inputs into the system)**	**Excluded (excluded from the system consideration)**
Controls Physical lifting device Ski lift operator Operator communication system Safety protocol Lift locomotion	Ski lift user Fuel Lift line markers (to funnel users into a line) Snow under the lift (natural or artificial) Ticket scanning machine	Snow depth Energy of user Energy of lift operator Price of lift pass Type of skis/snowboards used

4.1 Use Case-Using a surface lift at an Australian ski resort

<table>
<tr><td>Primary Actor : lift user</td><td>Scope: The Australian Winter Resort</td></tr>
<tr><td colspan="2">Stakeholders and interest</td></tr>
<tr><td colspan="2">Lift user- minimise waiting time in lift line, fast and easy trip up the mountain</td></tr>
<tr><td colspan="2">Lift operator - lift is easy to operate, low number of lift users meaning less work to do in the cold</td></tr>
<tr><td colspan="2">Lift owner/resort – lifts are constantly running at capacity, indicating that the resort is full of skiers and snowboarders thus profits are maximised</td></tr>
<tr><td>✚ Success Guarantees: Skier or snowboarder uses the surface lift with minimal waiting time, experiences no difficulty in using the lift and fast and efficient lift operation</td><td>▬ Minimal Guarantees: Skier or snowboarder ascents the mountains by way of the surface lift</td></tr>
<tr><td colspan="2">Trigger: Skier or snowboarder wishes to ascent to higher elevation</td></tr>
<tr><td colspan="2">Main success scenario</td></tr>
<tr><td colspan="2">1. Lift user enters lift line with minimal waiting time
2. Lift user mounts lift easily and safely
3. Lift transports user to higher elevation
4. Lift user disembarks</td></tr>
<tr><td colspan="2">1a. User waits in line before eventually entering lift
2a. Lift stops due to mechanical failure/someone falling off whilst mounting
2a1. User waits for problem to be resolved before commencing lift ride
3a. Lift stops during operation
3a2. User waits for problem to be resolved before recommencing lift ride</td></tr>
</table>

5.0 Requirements Analysis

5.1 Pairwise Analysis:

Pairwise analysis on each of the performance requirements was conducted. In this process, each performance requirement (safe operation, speed, durability, cost and adaptability) were directly ranked against each other. This resulted in a ranking for each of the performance requirements (1 = most important).

1. Safe operation
2. Speed
3. Adaptability
4. Durability
5. Cost

Fortunately this pairwise analysis yielded no design requirements of equal rankings, thus no further differentiation between requirements is needed. Of note is the fact that the equal magnitudes between each requirements' ranking does not translate to 'durability' (rank 4) being deemed four magnitudes less important than 'safe operation' (rank 1). Rather, these rankings purely represent an ordering. Additionally, 'safe operation' has been identified as a non-essential design requirement as certain surface lifts such as rope-tows which can give the user a rope burn if not used correctly are inherently less safe than T-bar surface lifts which minimize the risk of injury. Thus it was deemed necessary to classify 'safe operation' as a design requirement as varying factors which affect the safety of the ski lift can potentially make it both much more inclusive and efficient, thus safety directly affects the scope of the project.

5.2 Technical Performance Measures (TPM):

This stage in the engineering design process involves selecting the design requirements and further narrowing these down into design attributes. Design attributes are characterized by the fact that they are quantifiable. Many of these design attributes have already been stated in table 1 and but many of these have been reworded in table 3 to ensure that the new attribute is quantifiable. Each of these design attributes, associated TPM and direction of improvement is indicated in table 3 the House of Quality.

5.3 House of Quality (HoQ)

The HoQ is a step in the design process that highlights the relationships between each of the design attributes and design requirements. For this project, where applicable, performance metrics have been included as sourced from Dopplymayr which is a common Australian surface lift manufacturer. Although they are indicative of some of the desirable performance requirements of any design solution, the qualitative nature of the design problem means that the performance metrics are not absolute.

From the HoQ, certain interrelationships become evident. Clearly the design requirements of safe operation and speed which were previously identified as the two of highest importance have broad interrelationships with each of the design attributes. Interestingly, the design requirement of durability, which ranked number four in the pairwise analysis, had stronger interrelationships with the design requirements than ‘adaptability.’ This indicated that an emphasis will need to be placed on both of these requirements. Also, the design attributes of ‘maximum weight transported by single lift (kg)’ and ‘maximum operating wind speed’ were shown to affect a majority of the design requirements. Clearly these intrinsically mechanical properties of the design should be looked at in depth.

Another important feature from the HoQ is the performance metrics, which describe certain quantitative values which, ideally, the proposed solution should meet. Some of the performance metrics have been left blank such as ‘spacing between successive lifts,’ ‘cost of construction’ and ‘maintenance costs’ as these attributes largely depend on a number of variable factors in ski resorts: the required length of the lift; the range of user abilities (beginner to advanced) and the required vertical elevation which the lift must attain.

Table 3- The House of Quality with performance metrics indicated

Key 0 **No relationship** 1 **Weak relationship** 3 **Medium relationship** 9 **Strong relationship**	**Relative Importance**	**Design attributes**	**Speed of lift relative to the slope**	**Force on user**	**Operating height of lift**	**Maximum weight transported by single lift**	**Spacing between successive lifts**	**Lifting Capacity**	**MTBF**	**Range of operating temperatures**	**Maximum operating wind speed**	**Range of user heights**	**Range of operational slope gradients**	**Power Usage**	**Cost of construction**	**Annual Maintenance Costs**
Direction of improvement			↑	↓	↓	↑	↓	↑	↑	↑	↑	↑	↑	↓	↓	↓
Design Requirement																
Safety operation	1		9	3	3	1	3			1	1	1	1			
Speed	2		9	9		3		3			1		3	3	3	
Adaptability	3			3	1	1				3	3	3	1			
Durability	4					3		3	9	9	3				1	1
Cost	5					1		3	3					3	9	9
Metric (TPM)			m/s	N	m	kg	m	Ppl/hr	yrs	°C	Km/h	m	Degrees	kW/h	AUD ($)	AUD ($)
Performance Metric			3m/s	-	0m-	-	-	1200 ppl/hr	10 yrs	-	90km/h	-	-	-	-	-

6.0 Design Considerations

6.1 Concept Generation Tree

Since the problem has been identified as *improving* current surface ski lift technologies, all of the concepts generated were either modifications on existing surface lifts or new surface lift concepts. To define some relevant terms from figure 4, a 'non-detachable' surface lift is one whereby the lifting mechanism (T-bar, J-bar) is fixed to the winching cable, thus all lifts are fixed at a certain distance apart. 'Detachable' surface lifts, on the other hand, can be operated at either short of long distances between successive lifts, depending on the skill of the lift user. The final generated concepts are shown below in figure 4. A problem scoping boundary has been drawn onto the concept generation tree to indicate which concepts fall within the scope of this system. Evidently, the option of 'walking up the mountain' does not fall into the system scope since such a lifting mechanism requires no physical lifting device (such as a T-bar, J-bar) which was previously identified as an endogenous design consideration (Table 2).

Considering all possible surface lifts option, it is evident from some of the design solutions generated that some much better satisfy the design requirements. Whilst 'walking up the mountain' represents both a cheap and adaptable option, it is the slowest lifting type. In contrast, a 'modified T-bar' is safe, fast and potentially cost effective depending on the depth of modifications and thus it will be explored in more detail as a possible design solution.

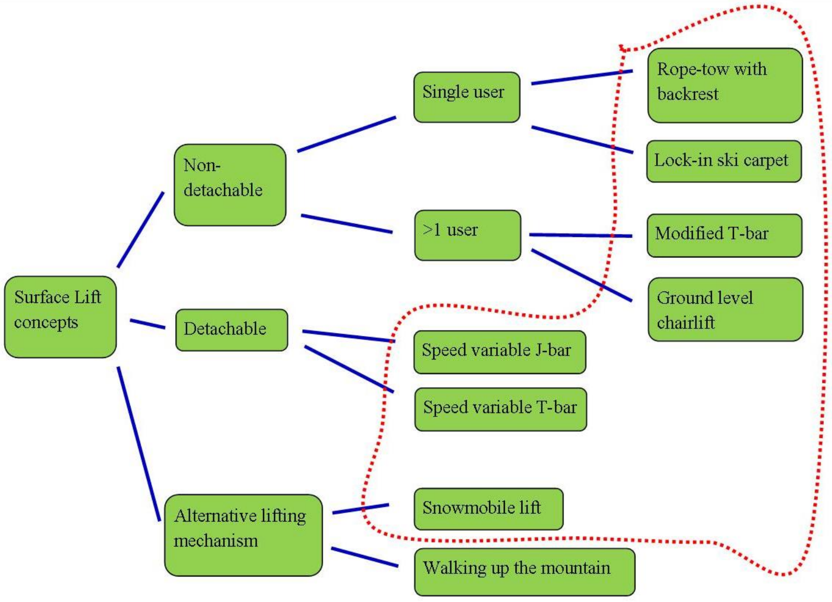

Figure 4: The Concept Generation Tree for potential design solutions

6.2 Analytical Testing on a Modified T-bar design

Progressive testing throughout the systems engineering design process allows initial flaws to be eliminated before they become larger, more time and money consuming issues (Blanchard & Fabrycky, 2011). A means of analytical testing is conducted below to illustrate the advantages of a two types of modified T-bar designs (figures 6b,c) against the present day T-bar design (figure 5 and figure 6a). It should be noted that for the design alternative shown in figure 6c, for a snowboarder, each leg would rest against the red support (so the back leg would sit in between the two red supports).

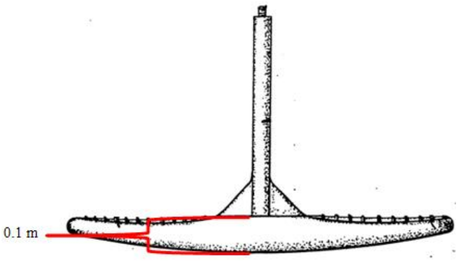

Figure 5: Present day T-bar design front view

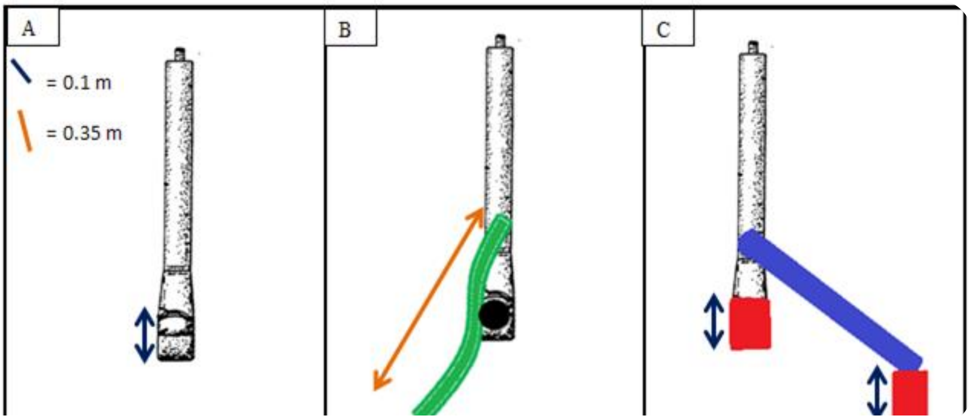

Figure 6: Side views of; [A] Present day T-bar design, [B] design alternative 1, [C] design alternative 2

Analysing the magnitudes of the distributed loadings on each T-bar design will indicate which design alternative best meets the design attribute of 'force on user.' For each analytical test, it is assumed that the equivalent distributed loading has a magnitude of *x* N. This number is arbitrary as it depends on the mass of the user, the gradient of the lifting slope and the speed of the lift.

Design [A] Recalling that for an evenly distributed load along a flat surface (and approximating the surface in figure 6c to be flat), the resultant loading is given by (y*z)N (figure 6).

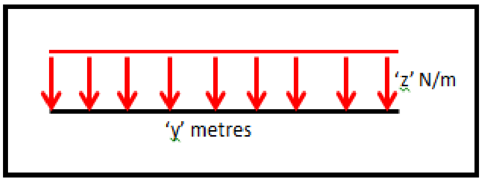

Figure 6- distributed loading along a flat surface

Design A	**Design B**	**Design C**
$x\ N = 0.1\ m\ \times z\frac{N}{m} \therefore z = \frac{x}{0.1}$	$x\ N\ = 0.35m\ \times z\frac{N}{m}\ \therefore z = \frac{x}{0.35}$	$x\ N\ = 0.2m\ \times z\frac{N}{m} \therefore z = \frac{x}{0.2}$

This analysis indicated that design alternative [B] provides the greatest load distribution, thus is represents the most comfortable alternative for both snowboarders and skiers using the E.S.S-bar. Also as shown in the preliminary design sketches in figure 3, the design only consists of one alternative attachment to the T-bar, therefore it would be easy to integrate into existing technology. This design should be further explored.

7.0 Logic and Function

7.1 Functional Flow Block Diagram

To continue to understand the functional operation of the surface lift system, it is necessary to develop an understanding of how components will function. This is accomplished by defining a set of discrete *functions* which any proposed design solution will have to perform in order to transport users to an area of higher elevation on a ski slope (Blanchard & Fabrycky, 2011). The allocation of these functions is conducted via a top-down approach, with broader top-level functions being defined initially, before successively lower-level sub functions are generated (Anon., 2001). The use of a Functional Flow Block Diagram (FFBD) shown in figure 7 illustrates this process of function partitioning. Certain key features of this schematic include; “Go and No-Go paths” (G and $\check{G}$) which represent functions whereby two possible outcomes are possible, one which compromises the systems function ($\check{G}$) and the OR gate which represents alternative paths that can be taken to reach the subsequent functional block. As indicated on the concept generation tree (figure 4), the design scope of the project has been indicated on the FFBD by a blue dashed line. The scope of this primarily surrounds the function of mounting the surface lift and how a modified T-bar design can improve the efficiency and inclusiveness of this specific function.

The FFBD highlights some important aspects within the surface lift system surrounding the lift mounting procedure. Clearly two main issues can occur during lift mounting and operation; the lift user falling off the lift and having to attempt re-mounting and the lift malfunctioning during operation. Whilst a modified T-bar design consisting only of an attachment to the existing T-bar lifting device (figure 2b) would not be able to reduce the likelihood of the lift malfunctioning during operation, it would be able to decrease the likelihood of the lift user falling off during the initial mounting stage. This is because the modified T-bar design (figure 2b) has an increased surface area for mounting with an additional adhesive surface. Reducing the number of people who failed to mount the lift on their first attempts would increase the lifting capacity of the lift, thus the efficiency of the lift would be improved. Another key point which the FFBD highlights are the fact that ‘mounting lift’ comprises of some third level operational functions. This validates the fact that a modified T-bar design would form a very minor addition to an already large system.

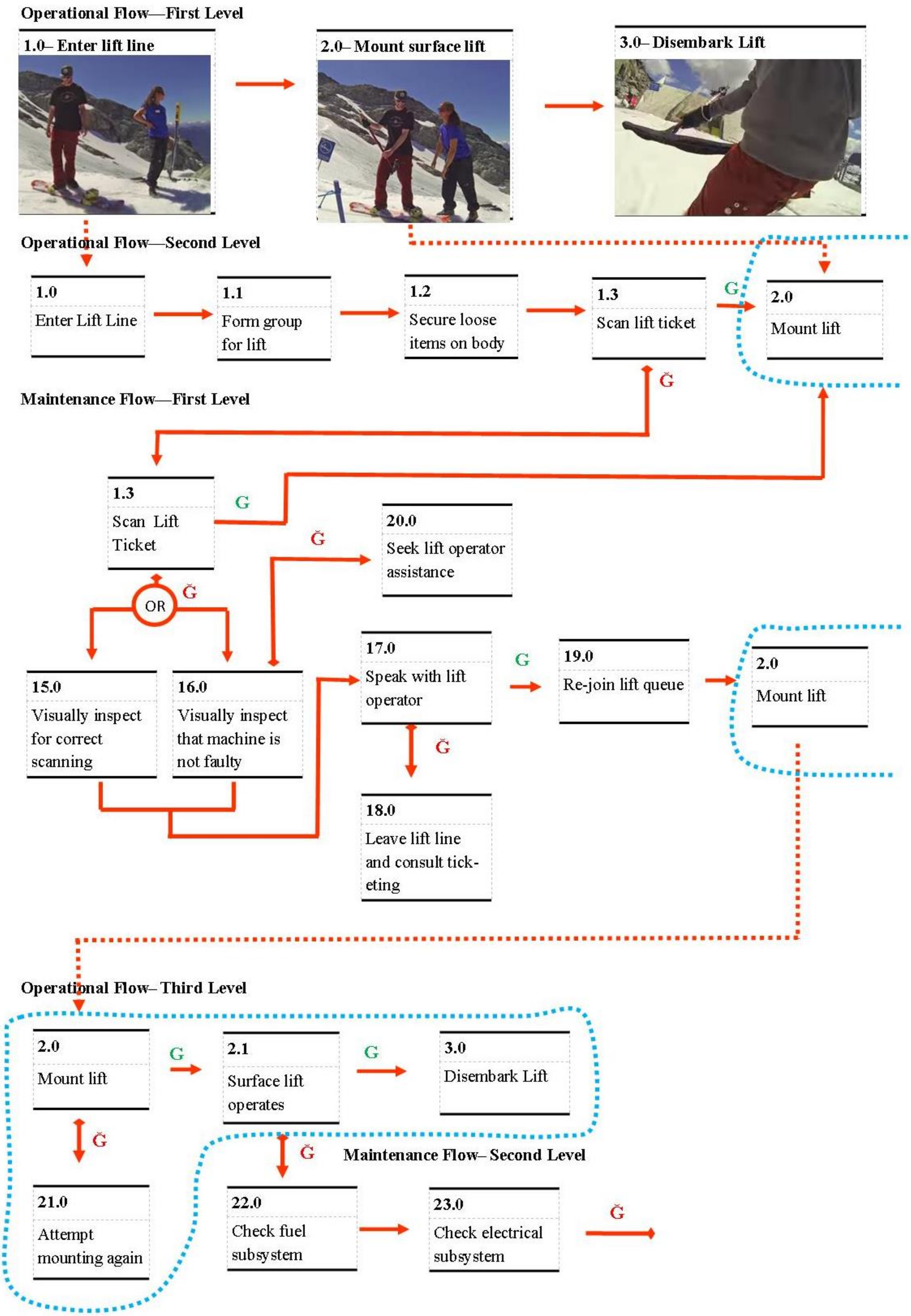

Figure 7: A Functional Flow Block Diagram (FFBD) for a typical ski resort surface lift. Images taken from (Tips, 2014)

8.0 Subsystem Integration

A design which best minimises its interactions with other subsystems is one which allows improved modularity and overall the best subsystem integration (Browne, 2013). The use of a Functional Block Diagram (FBD) as shown below in figure 8 allows the relationships between functions both inside and outside of the system boundary to be mapped.

8.1 Functional Block Diagram

For this project, the subsystems comprising the surface lift system were initially scoped (table 2). Four main subsystems were conceived; the locomotion system, the control system, the operator communication system and the physical lifting system. Relevant components pertaining to each system are indicated in addition to the likely inputs and outputs within the system. The difference between the control system and the operator communication system should be emphasised. The control system encompasses both the control of the lifting mechanism, conducted by the lift operator, as well as the control dictated by the user. User control within the surface lift system relates to the user forming a line and scanning their ticket whilst the lift operator control relates to assisting mounting on and off the lift. The operator communication system, conversely, only relates to the lift operator/s who communicates in order to ensure efficient operation of the lift.

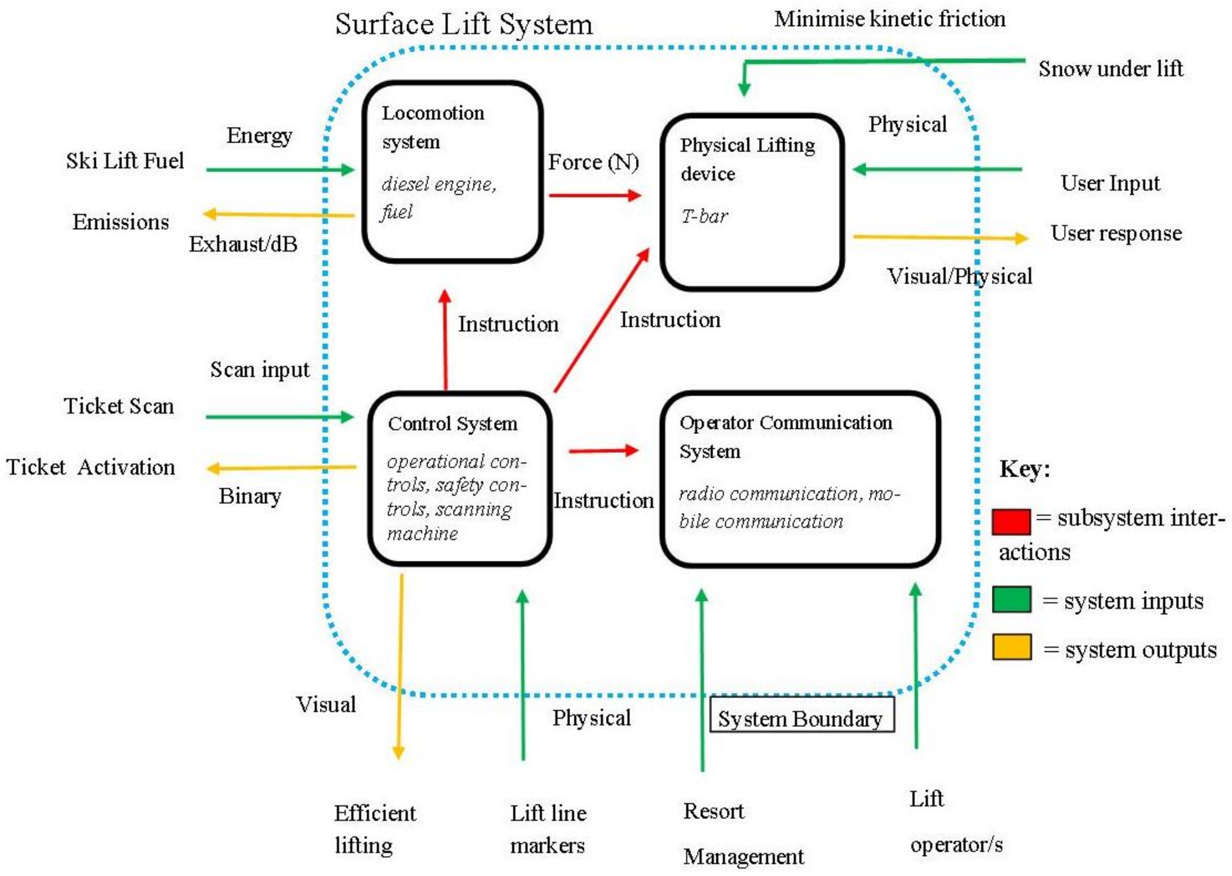

Figure 8: FBD for the Surface Lift System

The benefits of using a modified T-bar design are apparent with reference to this FBD (figure 8). Such a design solution would not interfere with any of the other subsystems within the surface lift, thus integration and implementation would be relatively easy. Considering the design solution in a more physical sense, since a modified T-bar design would not require alterations to the existing surface lift components, it represents a highly cost effective design solution. Additionally, Australia's two largest ski resorts in terms of skiable terrain, Perisher and Thredbo, each have 68% and 63% of all surface lifts as T-bars (Perisher, 2015) (Thredbo, 2015). Therefore a modified T-bar design solution would serve a majority of surface lift users.

An interesting consideration which the FBD highlights is the potential of combining the control and operation communication systems into one. This would eliminate the need for a human lift operator with alternative communication systems coming in the form of robotic assisted lift mounting and video lift surveillance. Such a drastic modification, however could reduce the safety of the lifting device which would not comply with this projects' design considerations as safe operation was previously identified as the most important customer requirement (HoQ table 3)

8.2 Attributes Cascade

The attributes cascade (table 4) is a method of directly relating the performance requirements to the relevant subsystems outlined in the FBD (figure 8). This is a very important stage in the design process as it allows the relationships between the subsystems and performance requirements to become more explicit, and ensures that the proposed design solution best meets these performance requirements. In developing an attributes cascade, the performance requirement of 'safe operation' will be deconstructed as this requirement was deemed the most important design consideration throughout this project. This requirement is then 'cascaded' into a series of primary and secondary attributes, the primary attributes of which are taken directly from table 1. When cascading the secondary attributes, the question was posed *what is necessary to achieve the primary attribute?*

Table 4: Attributes Cascade for the Performance Requirement of 'Safe Operation'

Performance Requirement	Primary Attribute	Secondary attribute	Related Subsystems
P1 Safe operation	A1 Correct operating speed	A1.1 level operating surface	BYSCP
		A1.2 variable speed control	LOC/CONT
		A1.3 Stop/start speed control	LOC/CONT
		A1.4 Operator view of lift	OPCOM
	A2 Low operating height	A2.1 Adjustable height control	BYSCP
		A2.2 Level surface for grooming snow	BYSCP
		A2.3 Snow drift catchment areas surrounding lift	BYSCP
	A3 Lift fastening mechanism	A3.1 Non-detachable lift fastener	CONT
	A4 Efficient physical lifting mechanism	A4.1 >1 user per lift	PHYS
		A4.2 Skier/snowboarder friendly	PHYS
	A5 Minimal force on user	A5.1 Maximise contact area on user	PHYS
		A5.2 Suspension in lift harness	PHYS
		A5.3 variable lift speed	LOC/CONT

Subsystem Key: LOC = locomotion, CONT = control, PHYS = physical lifting, OPCOM = operational communication, BYSCP = beyond the scope of the problem

Analysis of this attributes cascade reveals one key point about the subsystem based relationships with the performance requirement of 'safe operation.' This is the fact that the subsystems are largely independent of each other. Considering the proposed design in this context, the modified T-bar which is part of the PHYS subsystem, integrating such a design to meet the performance requirement of 'safe operation' poses minimal challenges since it only directly influences four secondary attributes. This is also advantageous because if some part of the design solution was to fail, the problem could be quickly identified as relating to one of the four secondary attributes indicated.

9.0 Life-cycle phases

9.1 A modified T-bar design with materials analysis

Modern day T-bar ski lifts are constructed using a polyurethane 'tee' section mould (Macfarlane, 1987). A possible E.S.S-bar design would consist of a new polyurethane mould forming an attachment on the 'tee' section of the lift. Such a mould has been CAD drawn and is illustrated in Appendix, figure A. The weight of the component was evaluated on CAD to be at 3700 g. This mould would be coated in thin layer of either fluoro silicone rubber or chloroprene to give the surface medium grip. A materials analysis of each of potential coatings is shown below in table 5.

Table 5: Materials Analysis for modified t-bar design, materials information sources from (rubber, 2005) (Chemspider, 2015) (Callister & Rethwisch, 2014)

	Elongation (%)	Useful temperature range (°C)	Weather resistance
Fluoro silicone	100-480	-60 to 205	Excellent
Chloroprene	100-800	-50 to 105	Excellent

Although it has a superior range of useful temperature operations, a better choice for the thin coating on the polyurethane would be chloroprene since it represents a much more commercially viable alternative. Likewise, the lower end of the useful operating temperature range pertains more to the elastic properties of the material and since the material will be used as more of a coating rather than a load bearing device, chloroprene is an ideal material choice. The combined materials choice of polyurethane and chloroprene renders the final design quite durable in outdoor winter conditions, satisfying this design requirement.

10.0 Testing and Communication

10.1 Tests and Verification

Whilst the attributes cascade (table 4) is a good method to illustrate the relationships between the performance requirements and subsystems the use of a weighted evaluation matrix allows a more quantitative calculation of how closely the proposed solution meets these performance requirements. Analytical testing has already been conducted on the attribute for 'force on user' and a means of conducting further testing on other design attributes is described below in table 6.

Table 6: Testing procedures outlined

Attribute to Test	Test Scope	Testing procedure	Pass/fail criteria
Range of user heights	Analytical	Using a fully drawn CAD model of the 'E.S.S-bar' surface lift, possible user height ranges are explored.	'E.S.S-bar' is considered operable whereby the lifting device sits below the lower back or above the back of the knee. This represents the possible range of lifting points.
Maximum weight transported by single lift	Proof of concept	a) Using a prototype lifting motor, maximum power outage could be examined. This would relate directly to the maximum weight that could be transported by a single lift. b) examining the strength of the materials involved in the lift (E.S.S-bar, lift cable connector, lift cable)	Device is considered with a 1.5 factor of safety for all strength tests on components.
Speed of lift relative to the slope	System prototype	For the lifting slope, the maximum lifting speed up the steepest section of the lifting slope will be examined. This speed can be sufficiently lowered or increased to ensure that the operating speed is $3ms^{-1}$.	Meets the performance benchmark or $3ms^{-1}$ as noted in table 3.
Lifting capacity	Analytical	Examined after the spacing between successive lifts has been finalised. Lifting capacity assumed to be when lift is in continuous operation with every lifting device full of users.	Meets the performance benchmark of 1200ppl/hr as noted in table 3.

10.2 Design Evaluation and Validation

A weighted evaluation matrix (table 7) has been used to compare the E.S.S-bar system design solution against two existing surface lift technologies in Australian resorts, T-bars and J-bars (figure 1a,c). Many of the evaluation values were given based on user knowledge and experience of these lifting devices. Attributes such as ‘lifting capacity,’ however were sources from a common surface lift manufacturer, Doppelmayr (Doppelmayr, 2015).

Table 7- Weighted Evaluation Matrix Comparison the E.S.S-bar, T-bar and J-bar

Design Requirement	**Scale** 5 = exceeds compliance 3 = full compliance 1 = partial compliance 0 = non-compliance 0*= could not be determined	**Weighting**		**Doppelmayr T-bar**		**E.S.S-bar**		**J-bar**	
		Rank	**Weighting**	**Relative Compliance**	**Weighted Value**	**Relative Compliance**	**Weighted Value**	**Relative Compliance**	**Weighted Value**
Adaptability	Range of user heights	3	1	1	1	3	3	5	5
	Force on user	3	1	1	1	3	3	1	1
Safe operation	Speed of lift relative to the slope	1	3	3	9	3	9		
	Maximum weight transported by single lift	1	3	3	9	3	9	1	3
Speed	Lifting Capacity	2	2	3	6	3	6	1	2
	Totals				26		30		11

As evident from table 7, the E.S.S-bar performs the best against the listed attributes. Since the E.S.S bar is a modification of existing T-bar technologies, the only areas which it performs better than ordinary T-bar’s were in the ‘range of user heights’ and ‘force on user.’ These two attributes, however, directly affect the product’s efficiency and inclusiveness thus the E.S.S-bar is a conclusively better design option than existing surface lifting technologies. This is an important design validation as it reaffirms that the E.S.S-bar is the best design alternative.

10.3 Future Steps and design communication

Construction and implementation of the E.S.S-bar is still a long way off, but a proposed implementation stage would involve testing on a range of slopes (flat towards steep) and a range of user abilities (beginner skiers/snowboarder to expert skiers/snowboarders). Additionally, the design should be communicated to resort patrons initially over the summer season through social media, similar to how Perisher resort communicated the progressive construction of their new ‘Freedom Quad’ chairlift over the 2013/2014 summer. Such a design communication involved weekly images of the construction progress to generate public interest. The optimum means of implementing the design would be to install the E.S.S-bar on one surface lift at each of the Australian resorts and use the customer feedback to then decide if full installation should be conducted or if the design should be re-worked.

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Appendix

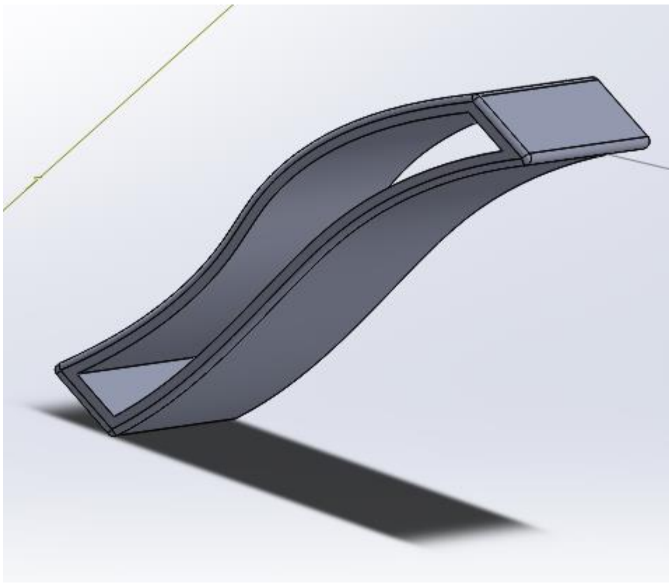

Figure A- CAD drawn model of the polyurethane shell as part of the E.S.S-bar