ÇUKUROVA ÜNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

PhD THESIS

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DEVELOPMENT OF A SOFTWARE FOR APPROPRIATE COSTING, TECHNICAL CALCULATION AND VISUAL SIMULATION OF WEFT KNIT FABRIC

DEPARTMENT OF TEXTILE ENGINEERING

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ÖZ

DOKTORA TEZİ

ATKILI ÖRME KUMAŞLARIN MALİYETİ, TEKNİK HESAPLAMALARI VE GÖRSEL SİMÜLASYONU İÇİN BİR YAZILIM GELİŞTİRİLMESİ

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Hazır giyim imalatında önemli hammadde kaynakları arasında yer alan örmecilik, yerel ve dünya pazarında dokumadan sonra ikinci büyük endüstridir. Bu tez çalışmasında örme endüstrinin gelişimine katkı sağlamak için üç modül içeren bir yazılım geliştirilmiştir. İlk modül, halihazırda kullanılan ve doğru maliyet bilgisi sağlayamayan geleneksel maliyetlendirme yaklaşımının yerini alması beklenen Faaliyete Dayalı Maliyetlendirme sistemidir. İkinci modül, istenen özelliklere sahip kumaş üretiminde kullanılan bir dizi standart denklem ile çeşitli kumaş parametrelerini hesaplamaktadır. Üçüncü modül, tamamen işlevsel bir yapı geliştirme ortamı sağlamaktadır. Geliştirilmiş olan yazılım verilen kumaş yapısını otomatik olarak doğrulamakta, tekrarlayan desenleri tespit etmekte ve o kumaş için en uygun kam kurulumunu ve iğne düzenini hesaplamaktadır. Geliştirilmiş olan yazılım sayesinde ayrıca, kumaş tasarımcısının gerçek kumaşı atanan renklerle örgü raporuna uygun olarak makinede üretilmeden önce görmesine ve değerlendirmesine olanak tanıyan, kumaşın görsel bir simülasyonu görüntülenmektedir.

Anahtar Kelimeler: Örgü, örgü geometrisi, faaliyete dayalı maliyetlendirme, örgü kumaş, görsel simülasyon.

ABSTRACT

PhD THESIS

DEVELOPMENT OF A SOFTWARE FOR APPROPRIATE COSTING, TECHNICAL CALCULATION AND VISUAL SIMULATION OF WEFT KNIT FABRIC

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Knitting, as a backward linkage for readymade garments, is the second largest industry in the domestic and worldwide market, behind wovens. A software with three modules has been developed to aid in the further strengthening of this industry. The first module is the Activity Based Costing system, which is expected to replace the currently used traditional costing approach incapable of providing accurate cost information. The second module calculates various fabric parameters using a set of standard equations that assist technicians in producing a fabric with expected specifications. The third module provides a fully functional fabric development environment. The developed software automatically validates the given fabric structure, detects recurrent patterns, and calculates optimal cam setup and needle arrangement for that fabric. Finally, it displays a visual simulation of the fabric based on the notation diagram with assigned colors, allowing the fabric designer to view and assess the actual fabric before it is produced on the machine.

Key Words: Knitting, knitting geometry, activity-based costing, knit fabric, visual simulation.

GENİŞLETİLMİŞ ÖZET

2019 yılında küresel GSYİH'nın yüzde 2,1'ini oluşturan küresel hazır giyim sektörünün 2025 yılına kadar 2,247 milyar ABD dolarına yükselmesi beklenmektedir (Statista, 2022). Bu alanda, dünya çapında örme kumaş pazarının, 2018'deki 23,8 milyar ABD Doları değerinden 2025 yılına kadar 35,7 milyar ABD Dolarına, 2019'dan 2025'e kadar yüzde 6,0 bileşik yıllık büyüme oranıyla (CAGR) artması beklenmekte (Grand View Research, 2022) ve 2031 yılına kadar yaklaşık 40 milyar ABD dolarına ulaşacağı tahmin edilmektedir (FactMR, 2022).

2018 yılında 16,2 milyar ABD Doları hazır giyim ihracatı (GÜLLE, 2019) ve 17,7 milyar ABD Doları hasıla (Türkiye İhracatçılar Meclisi, 2022) elde eden Türkiye, 2019 yılında global pazardaki %2,70’ lik payı ile Dünya’ nın en büyük 7., AB’ nin ise en büyük 3. tedarikçisi olmuştur (Directorate General of Exports, 2021). 2004 yılı sonunda Dünya Ticaret Örgütü Tekstil ve Hazır Giyim Anlaşması (ATC) uyarınca küresel tekstil kota sistemi sona erdikten sonra dahi Türk hazır giyim ihracatı artış göstermiştir. 2019 yılı Türkiye hazır giyim ihracatında dokuma ürünlerin payı yüzde 41,51, örme ürünlerin payı ise yüzde 58,49 seviyesindedir. Böylece dünya örme giyim ihracatının yüzde 3,80'ini gerçekleştirmiş ve ihracatçı ülkeler arasında altıncı sırada yer almıştır (Directorate General of Exports, 2021). 2021 yılında Türkiye'nin hazır giyim ve konfeksiyon ihracatı, yıl içindeki ülke toplam ihracat değerinin %8,99'u olan 20,25 milyar ABD dolarına ulaşmıştır (Türkiye İhracatçılar Meclisi, 2022). 2020 yılı itibarıyla tekstil sektörü ve alt sektörlerinde toplam 1,67 milyon kişi istihdam edilmektedir (Daily Sabah, 2020). Taşımacılık gibi lojistik, ihracat ithalat ticareti, turizm, bankacılık ve iletişim üzerindeki etkisi, döngüsel ekonomi ve bu destekleyici sektörlerde işe yerleştirme oranı dikkate alındığında, bu sektörün ulusal ekonomide üzerindeki etkisi daha da büyük olmaktadır. Örme kumaşlar günlük giyim, kışlık giyim, pajama, eşarp, bere ve eldiven gibi birçok alanda kullanılmaktadır. Kırışmaya dayanıklı, esnek, yumuşak ve rahat giysilere artan tüketici tercihlerine parallel olarak son yıllarda örme

kumaşların denim giysilerde kullanımında da artış görülmektedir. Atkılı örme ürünlerin düşük maliyeti, esnek yapısı ve nispeten basit üretim süreçleri sayesinde önümüzdeki dönemde de pazarda hakimiyetini sürdürmesi beklenmektedir (FactMR, 2022).

Bu çalışma, ülke ekonomisi için büyük bir öneme sahip olan ve istihdama önemli katkı sağlayan örme sektörünün teknolojik eksikliklerine odaklanmıştır. Belirlenen zayıf noktalar, ürün maliyet sistemi, karakterizasyon parametreleri, kumaş tasarımcıları için yeterli tasarım araçları ve tasarlanan kumaşı gerekli özelliklere sahip bir makinede üretmekten sorumlu tasarımcılar ve teknisyenler arasındaki boşluktur.

Günümüz pazarında maliyet, rekabet edebilirliğin en önemli faktörüdür (Barfield et al., 2002). Pazardaki rekabet mükemmel kalitede ve en düşük maliyetle ürün veya hizmet üretimi gerektirmektedir. Uygun bir maliyet modeli kullanmak ve maliyetleri etkin bir şekilde kontrol etmek, rakiplerine karşı avantaj sağlamaktadır (Siguenza-Guzman et al., 2013). Otomasyon, teknoloji ve bilgisayar sistemleri, maliyetleri emek yoğundan sermaye yoğuna kaydırarak küresel pazarda rekabetin yükselişine önemli bir katkıda bulunmuştur (Barfield et al., 2002). Genel giderler, doğrudan malzeme ve işçilik maliyetlerinin aksine, giderek maliyet yapısının ana itici gücü haline gelmektedir. Maliyet sistemi, uzun vadeli sürdürülebilirliği sağlamak için, firmadan tedarik edilen ürün veya hizmetin mantıksız piyasa fiyatları nedeniyle rekabet gücünü kaybetmesini önlemelidir (Türkiye İhracatçılar Meclisi, 2022). Geleneksel maliyetleme sistemi, hammadde maliyetlerinin ve doğrudan işçilik maliyetinin doğrudan ürüne yüklenmesi ve dolaylı maliyetlerin doğrudan işçilik veya makine saatlerine veya üretim birimlerine göre bölünmesi temel fikrine dayanmaktadır. Otomasyondaki ilerlemeler, dolaylı maliyetlerin aksine doğrudan maliyetlerin ağırlığının azalmasına neden olmuştur. Bu maliyetlendirme yaklaşımı, maliyet etkeni yalnızca hacme bağlıysa ve bu nedenle çoğunluk için doğru maliyet bilgisini tahmin edemediği varsayılırsa bir bozulma sinyali verebilir. (Siguenza-Guzman et al., 2013). Tekstil üretim hatlarında maliyet modellerinin uygulanmasına yönelik özel sistemler, büyük bir tür organizasyona uyacak şekilde tasarlanmış ve güncellenmiş sistemler kadar yaygın değildir. Bu sektör ülke ekonomisi açısından büyük bir öneme sahip olmasına rağmen, sık süreç değişimi yaşanması, ürün çeşitliliği, yoğun işçi etkileşimi ve bilgisayar tabanlı maliyetlendirme sistemi geliştirme eksikliği nedeniyle örme fabrikalarında genel kabul görmüş bir maliyetlendirme modeli bulunmamaktadır. İşletmelerin bir kısmı geleneksel maliyet modellerini kullanırken, bir kısım işletmeler kendilerine özgü hesaplama yöntemini geliştirmişlerdir (Lanen et al., 2016).

Örme yapıların özelliklerini açıklamak için önerilen geometrik modeller dokuma kumaş modellerine göre yetersiz kalmaktadır. Önerilen modeller, rib (Kurbak, 2009) veya interlok (Jeddi & Dabiryan, 2008) örgülere az önem verilerek genellikle düz örgüler veya süprem örgüler (Pavko Čuden, 2010) üzerine kurulmuştur. Bu eksiklik karmaşık üç boyutlu lif, iplik ve kumaş yapılarından kaynaklanmaktadır. Örgü kumaşların özelliklerini kesin olarak açıklayabilecek evrensel bir matematiksel model veya formülasyon bulunmamaktadır (Frederick Thomas Peirce, 1937). Örme kumaş üretiminde hammadde seçimi ve makine ayarlarının yapılması için üretimden önce kumaşın karakterizasyonu ve özelliklerinin tahmin edilmesi gerekmektedir. Bu nedenle denemeleri en aza indirmek amacıyla iplik, kumaş ve makine parametreleriyle ilgili denklemler kullanılmaktadır (Pavko Čuden, 2010). Sektördeki teknik çalışanlar tarafından oluşturulan, bir kısmı geometrik modellere dayanan ve dünyanın çeşitli yerlerinde farklı şekillerde kullanılan bu denklemler toleranssız uygulanamamakta ve tahminleme amacıyla kullanılmaktadır. Fakat örme kumaşların karakterizasyonu amacıyla geliştirilmiş olan geometrik modeller dokuma yapılara kıyasla hala yetersiz kalmaktadır (Cirio et al., 2017). Örgü malzemelerinin özelliklerini kesin olarak tanımlayabilen (Frederick Thomas Peirce, 1937) yaygın olarak kabul edilen bir matematiksel model (Nutting & Leaf, 1964) veya formülasyon bulunmamaktadır. Doğal ve üretim faktörlerine bağlı olarak çeşitlenmiş lif, iplik ve kumaş yapıları çalışmaları zorlaştırmaktadır. Bu durumun başlıca nedeni lif, iplik ve kumaş yapılarının doğal karakterleri ve üretim faktörlerinin değişkenliğidir.

Günümüzün dinamik moda endüstrisinde, yeni desenler, yapılar ve renk karışımlarının rekabetçi oranlarda ve zamanında geliştirilmesi kritik öneme sahiptir (Ray, 2012a). Küresel arenada rekabet eden işletmeler için artık daha hızlı sistemler ve daha hızlı tepki süreleri bir zorunluluk haline gelmiş ve sonuçta imalat şirketlerine dayatılan talepleri artırmıştır. Bununla birlikte, şirketlerin hızla değişen pazar taleplerine daha iyi cevap verebilmek için müşteri odaklı stratejilere olan ihtiyacı giderek daha fazla fark etmesine rağmen (Mok et al., 2013), örme kumaş üretimi alanındaki uygulama ve talep arasında, özellikle tasarım ve istenen kalitede üretim arasında uyumsuzluk vardır. Sürekli değişen pazara ayak uydurmak için tasarımcılar artık değişen trendlere veya mevsimlik modaya ayak uydurmak için her yıl beş civarında koleksiyon hazırlamaktadır (Jenkyn-Jones, 2011). Yapısal yenilikler ve renk kombinasyonu olanakları neredeyse sınırsızdır (Meißner & Eberhardt, 1998). Başarılı bir örgü tasarımcısı olmak, hem yaratıcılığı hem de çok çeşitli teknolojik ve terbiye bilgisini gerektirmektedir. Tasarımcı iplik kalitelerine, ürün tasarımına, örme ve üretim tekniklerine ve diğer ilgili konulara hakim olmalıdır (Francis & Sparkes, 2011). Sonuç olarak, belirli bir pazar ve son kullanım için estetik çekiciliği pratik performansla uzlaştırma gibi zorlu bir sorunla karşı karşıya kalınmakta (Redmore, 2011) ve tasarım sürecinde teknik hesaplamalara ihtiyaç duyulmaktadır. Tasarımcı, örgü kumaş görsel simülasyon teknolojisini kullanarak renkleri değiştirebilmeli ve etkisini anında gözlemleyebilmeli, renk ve yapının değişimini birlikte inceleyebilmelidir (Yordan Kyosev & Renkens, 2010). Halbuki örgü kumaş tasarımcılarının elinde dokuma veya giyim endüstrilerindeki meslektaşlarıyla aynı düzeyde tasarım araçları bulunmamaktadır (Groller et al., 1995). Bu durum örgü yapıların karmaşıklığından, genel kabul görmüş örgü geometrisinin yokluğundan veya bu tür sistemleri kullanacak olan örgü fabrikalarının daha düşük finansal kapasiteye sahip olmasından kaynaklanmaktadır. Atkı örme makinelerinde önemli ilerlemeler kaydedilmiş olmasına ragmen ekonomik potansiyel olarak istenen seviyelere ulaşılamamıştır (E. J. Power, 2018). Tasarımcılar için sınırlı kaynak ve teknisyenlerle olan teknolojik bağlantının yetersizliği nedeniyle, tasarımcılar zaman zaman tasarımlarının tam olarak makinede üretilmediğinden şikayet etmektedirler. Diğer yandan teknisyenler ise tasarımcıların üzerinde çalıştıkları makinenin teknik kapasitesini anlamadıklarını düşünmektedir. Bu iki meslek gurubu arasındaki anlaşmazlık, teknoloji geliştikçe daha da artmaktadır (Au, 2011). Bu nedenle, yuvarlak örme için, yapısal tasarım özgürlüğü sunan, renk kombinasyonu esnekliğine sahip ve tasarım ile makine kısıtlamalarını birleştirebilen ve aynı zamanda herhangi bir örgü kumaş tasarım departmanı için maliyeti ucuz olan, bilgisayar destekli bir tasarım sistemi gereklilik haline gelmiştir.

Bu çalışma, bir örme kumaş üretim fabrikasında maliyetlendirme sistemini analiz etmeyi ve tüm örme endüstrilerine yaygın olarak uygulanabilecek Faaliyet Tabanlı Maliyetleme sisteminin uygulanması için gerekli algoritmaları ve yazılımı geliştirmeyi amaçlamaktadır. Yazılım geliştirme çalışmaları ayrıca, tasarımcıların parametrik denklemler ile kumaş karakterizasyonu yapabilecekleri bir modül ve üretimde teknik kısıtlamalarla uyumlu olarak yapısal tasarım ve renklendirme yapabilecekleri bir modül içermektedir. Optimum makine üretim parametrelerinin elde edilmesi sayesinde tasarımcılar ve teknisyenler arasındaki anlaşmazlıkların azalması sağlanacaktır.

EXTENDED SUMMARY

The global apparel industry, which accounted for 2.1 percent of global GDP in 2019, is expected to increase to US$ 2,247 billion by 2025 (Statista, 2022). Within this domain, the worldwide knit fabric market is expected to increase from its 2018 value of USD 23.8 billion to US$ 35.7 billion by 2025, at a compound annual growth rate (CAGR) of 6.0 percent from 2019 to 2025 (Grand View Research, 2022) and it is projected to reach nearly US$ 40 billion by 2031 (FactMR, 2022).

In 2018, Turkey's export value from apparel sector was US$ 16.2 billion (GÜLLE, 2019) but earning US$ 17.70 billion from this sector (Türkiye İhracatçılar Meclisi, 2022), Turkey became the world's 7th largest supplier and the EU's 3rd largest supplier in the apparel business with a global market share of 2.70 percent, in 2019 (Directorate General of Exports, 2021). Even after the global textile quota system expired at the end of 2004 in accordance with the World Trade Organization Agreement on Textiles and Clothing (ATC), Turkish clothing exports increased. Statistics shows that, among the Turkey's apparel export in 2019, woven items had a piece of 41.51 percent whereas knitted items took a share of 58.49 percent. Thus, it accounted for 3.80 percent of the world's knitted apparel exports and placed sixth among exporting nations (Directorate General of Exports, 2021). In 2021, Turkey's clothing and apparel export reached US$ 20.25 billion which was 8.99% of its total export value in the year (Türkiye İhracatçılar Meclisi, 2022). A total of 1.67 million people were employed in the textile industry and its subsectors as of 2020 (Daily Sabah, 2020). This sector's economic impact in national economy will be even greater if logistics like transport, export import commerce, influence on tourism, banking and communication, circular economy and job placement in these supporting sectors are taken into account. There are many uses for weft knitting, such as for casualwear, leisure clothing, winter clothing, pajamas, scarves, caps and gloves. Fabric type such as plain or jersey, rib, interlock and all part of this technique. As consumers' preferences evolve toward wrinkle resistant, flexible, soft, and comfy textiles, knitted fabric has seen an uptick in its use in denim clothes in the recent years. Reports suggest that the domination of weft knitted textiles will continue in the coming days also because of their low cost, better elasticity, and simpler manufacturing process (FactMR, 2022).

As previously said, the textile and clothing industries are critical to the national economy and employ a large number of people, thus our research focused on the sector's technological shortcomings and worked with them. According to a thorough analysis of the market, the weak points identified are the product costing system, characterization parameters, adequate design tools for fabric designers, and the gap between designers and technicians responsible for producing the designed fabric in a machine with needed characteristics.

In today's market, cost is the most crucial factor of competitiveness since it gives essential information for decision making (Barfield et al., 2002). Competitors all desire a product or service that is of excellent quality and reasonably profitable yet at the lowest feasible cost that others can't provide. Utilizing an appropriate cost model and effectively controlling costs allows them to get an advantage over their rivals while also ensuring long-term viability (Siguenza-Guzman et al., 2013). Automation, technology, and computerization have made a substantial contribution to the rise of piercing competition in the global market by shifting costs from labor-intensive to capital-intensive (Barfield et al., 2002). Overhead costs are progressively becoming the primary driver of the cost structure, as opposed to the direct material and labor costs. In order to maintain long-term sustainability, therefore, the costing system must ensure that the supplied product or service from the firm will not lose its competitiveness due to illogical market prices. The traditional costing system was based on the basic idea that raw material costs and direct labor cost were to be directly allocated to the product and the indirect costs to be divided according to the proportion of direct labor or machine hours or units of production. Due to automation advances, the weight of direct costs has dropped in contrast to indirect costs, and this costing approach may give a distortion signal if the cost driver depends solely on volume, and therefore deemed to be unable to estimate accurate cost information for the majority of organizations (Siguenza-Guzman et al., 2013). Dedicated systems for the application of cost models in textile production lines are not as common as systems that have been completely redesigned and updated to match a big kind of organization. Although this sector is highly promising in the national economy, there is no generally accepted costing model to be acceptable in all knit factory because of the frequent process variation, product variety, massive worker interaction, and absence of computer-based costing system development. Traditional cost models are still used by some organizations; others have devised their own methods; and still others are attempting to adopt more recent cost models (Lanen et al., 2016).

To explain the properties of knitted structures, the geometrical models proposed so far are still inadequate comparing to the woven fabrics' models. Again, for the most part, the models proposed are based on plain knits or single jerseys (Pavko Čuden, 2010), with little consideration given to the double jersey, such as rib (Kurbak, 2009) or interlock (Jeddi & Dabiryan, 2008). This lack is often attributed to the complex nature of intermeshing in 3D space, variable properties of fiber, yarn and fabric due to natural and manufacturing parameters. There is no universally established mathematical model or formulation that can explain the properties of knit fabrics without uncertainty (Frederick Thomas Peirce, 1937). But as a dominant business sector, knit fabrics also requires characterization, also requires property prediction before going to actual production for selection of raw materials and setting of machine parameters. Thereby, for the sake of minimizing trials and keep the business on track, a set of equations are used relating yarn parameters, fabric parameters and machine parameters (Pavko Čuden, 2010). These equation sets are sometimes deduced by technical persons in the industry, some of them can be related to geometrical models but none of the full sets does go to any single source and none of the equations is applicable without tolerance, therefore, they are used as estimation. Since these equations are not always universally established, they can be used in various forms in various locations of the world. The geometrical models so far developed to explain the characteristics of knitted structures are still unsatisfactory in comparison to the models of woven materials (Cirio et al., 2017). There is no commonly accepted mathematical model (Nutting & Leaf, 1964) or formulation that can describe the features of knit materials without ambiguity (Frederick Thomas Peirce, 1937). The varied qualities of fiber, yarn, and fabric owing to natural and manufacturing factors are can be attributed for this deficiency. Knit textiles require characterization and property predication before manufacturing in order to choose raw materials and set machine settings for knitting or to minimize recovery processes in finishing levels. Therefore, a set of equations connecting yarn parameters, fabric parameters, and machine parameters are employed in order to minimize trial and error and keep the business on track (Pavko Čuden, 2010). Technical personnel in the industry may extract parts of these equation sets from geometrical models; nevertheless, none of the whole sets goes to any one source, and none of the equations is applicable without tolerance, rather they are used as estimations. Because they haven't been uniformly established, these equations can be used in a variety of forms throughout the world. It came out essential that, these equations be presented to the technical person via software module so that when needed, they can use this module in the easiest way with minimum errors.

In today's dynamic fashion industry, it is critical to develop new patterns, structures, and color mixes in the design at competitive rates and in a timely way (Ray, 2012a). Faster systems and faster reaction times are now a must for businesses competing on the global arena, increasing the demands imposed on manufacturing companies even further. However, despite the fact that companies are increasingly realizing the need for customer-centric strategies in order to better respond to rapidly changing market demands (Mok et al., 2013), there are significant gaps between practice and demand in the field of knitted fabric production, particularly in terms of development cycle and fitting quality manner. To keep up with the ever-changing market, designers now produce up to five collections each year, or even more, in order to keep up with shifting trends or seasonal fashion (Jenkyn-Jones, 2011). The possibilities for combining intermeshing loops for structural innovation and color combination are virtually limitless (Meißner & Eberhardt, 1998). It takes both creativity and understanding of a broad variety of technological and finishing restrictions to be a successful knit designer. They must be familiar in yarn qualities, product design, knitting and production techniques, and other related topics (Francis & Sparkes, 2011). As a result, they are faced with the tough problem of reconciling aesthetic appeal with practical performance for a given market and end-use (Redmore, 2011), and they require technical computational help at the center of the design process. Designers should be able to modify the colors and observe the effect immediately, as well as examine how color and structure work together (Yordan Kyosev & Renkens, 2010) using the knit fabric visual simulation technology. Unfortunately knit fabric designers continue to lack the same level of access to design tools as their counterparts in the weaving or clothing industries (Groller et al., 1995). These may be due to the intricacy of intermeshing, the absence of generally approved knitting geometry, or the less appealing market for such systems, with smaller in nature knit factories having lower financial capabilities. Weft knitting machines have seen significant advancement, but the technology is still not being exploited to its full economic potential (E. J. Power, 2018). Because of the limited resource for designers and technological gaps with technicians, designers occasionally complain that their designs are not exactly produced in the machine, but technicians think that the designers do not understand the limitation of the machine they are working on. It appears that this dispute between the two professions is becoming wider as technology grows more advanced (Au, 2011). Therefore, a computer-aided design system for fine-gauge circular knitting that can combine structural design freedom, color combination flexibility, and machine restrictions, while also being inexpensive to any knit fabric design section is essential.

This research work intends to analyze the nature of costing system in a knit fabric production factory and develop the necessary algorithm and software for implementation of the Activity Based Costing system which can be fit for all knitting industries commonly. Furthermore, it is intended to include a module for fabric characterization with available parametric equations, and a module that will allow designers to combine structural variation and color combination to be applied in designs that are compatible with the technical constraints in the production machines. At the same time, it will display the optimal machine setup parameters in order to reduce the gap between designers and technicians.

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ABBREVIATIONS

ABC : Activity Based Costing
ATC : Agreement on Textiles and Clothing
CAD : Computer-Aided Design
CAGR : Compound Annual Growth Rate
CAM : Computer Aided Manufacturing
GDP : Gross Domestic Product
GPU : Graphics Processing Unit
GSM : Grams per Square Meter
PBC : Process-Based Costing
QSR : Quick Service Restaurant
RGB : Red, Green, Blue
RPM : Revolution per Minute
SRS : Stereotactic Radiosurgery
TPI : Twist per Inch
UGC : University Grants Commission

1. INTRODUCTION

1.1. From Fiber to Fabric

Textile was originally used to refer to woven fabrics (J. Wilson, 2011). It is derived from the Latin verb texere, which means to weave, but is currently used to refer to 'any manufacturing process using fibers, filaments, or yarns with a high length-to-thickness ratio' (Spencer, 2001a). Despite their two-dimensional nature, textiles differ structurally from other flat materials (X. Chen & Hearle, 2010). Fiber to yarn conversion is a two-step process that includes spinning preparation and the actual formation of yarn. Filament yarns are made by grouping or twisting a large number of long, continuous fibers whereas spun yarn is made by twisting together short staple fibers (Schröder et al., 2012). Depending on how the yarn is formed and how the fibers are arranged, different methods have varying levels of quality (Neckář & Vyšanská, 2012).

Fabrics are two-dimensional plane-like structures made of textile materials with reasonable elongation and flexibility (Ray, 2012h). This yarn- or fiber-based construction can be used to manufacture garments and home textiles, as well as for industrial uses. When we cut and sew a fabric to our body's measurements, we create a garment (Ray, 2012l). Fabric can be produced in a variety of ways such as weaving, knitting, knotting and twisting together strands. There are a number of ways to make nonwoven and felted fabrics directly from webs of fibers (X. Chen & Hearle, 2010; J. Wilson, 2011). When it comes to creating fabric, weaving and knitting through mechanical manipulation of yarn is the most versatile (Spencer, 2001a).

Around 7000 B.C. in the Middle East, weaving was first developed (Cooke, 2011). It is the method of creating fabric by interlacing two sets of yarns so that they cross each other at right angles. In weaving, the transverse strands are referred to as "weft," or "filler," and the lengthwise ones as "warp." The outer edges of most woven fabrics are formed in a way that prevents raveling; these are known as selvages (X. Chen & Hearle, 2010). When viewed in historical context, knitting is a relatively recent art form. It is possible that weft knitting, which dates back to the third or fourth century AD, was developed in Egypt (Cooke, 2011). There are many different ways to knit, but the name "knitting" refers to the act of generating fabric by inter-looping a single or a set of yarn. In a knitted construction, there are rows and columns of intermeshed loops (Ray, 2012q; Spencer, 2001k). Using the freshly fed yarn, each needle hook makes a new loop by bringing the new loop through the old loop first (Spencer, 2001l). With an approximately 20 percent stake, knitting is the second most common method of fabric production (Ray, 2012h).

As mentioned, woven fabrics are produced by interlacing two sets of yarn, the production requires a greater number of preparatory processes, fabrics are comparatively rigid, less stretchable, low wrinkle resistant, less porous and dimensionally more stable. Knitting on the other hand employs inter-looping one or one set of yarns (X. Chen & Hearle, 2010), requires less preparatory process, simple and quick production technique (Çoruh & Çelik, 2014) fabrics are comparatively soft, stretchable, higher wrinkle resistant, highly porous and wrinkle resistant due to being low investment project compared to wovens, modern knitting machine offers the facility of seamless shaped garments ready to wear (Ray, 2012l). Design flexibility is high and the fabric is known for extra comfort than woven fabrics warm countries. The preparatory process of knitting does not require extra winding, warping and sizing, offers minimum processing wastage and yarn can be used directly from cones in weft knitting. The product ranges from internal to out wear garments to technical applications (Cooke, 2011; Ray, 2012h).

Dry laid carded webs were primarily made using modified textile processing machines, and the term "nonwoven" has been used to describe them for almost half a century (A. Wilson, 2007). Nonwoven textiles are built on a foundation of fiber webs stitched or entangled together using a variety of methods and thereby avoiding traditional weaving or knitting process. Fibers can be entangled through needle-punching, felting, or the use of adhesives. Natural or synthetic fibers in staple or continuous form can be used to make the fabric (Das, 2014; J. Wilson, 2011).

1.2. Knitting Terminology

Loop: loop is the basic unit of knitted structure and is defined as curve of yarn that bends uniformly and crosses itself and meshes with others (Iyer et al., 2004). From structural view, if it passes through from back to front of the old loop, it is called face loop (Ray, 2012g). When it passes from front to back, it is back loop. Generally, on the face side of the fabric, legs of the loop are visible and heads are invisible. Figure 1.1 shows the components in a knitted structure.

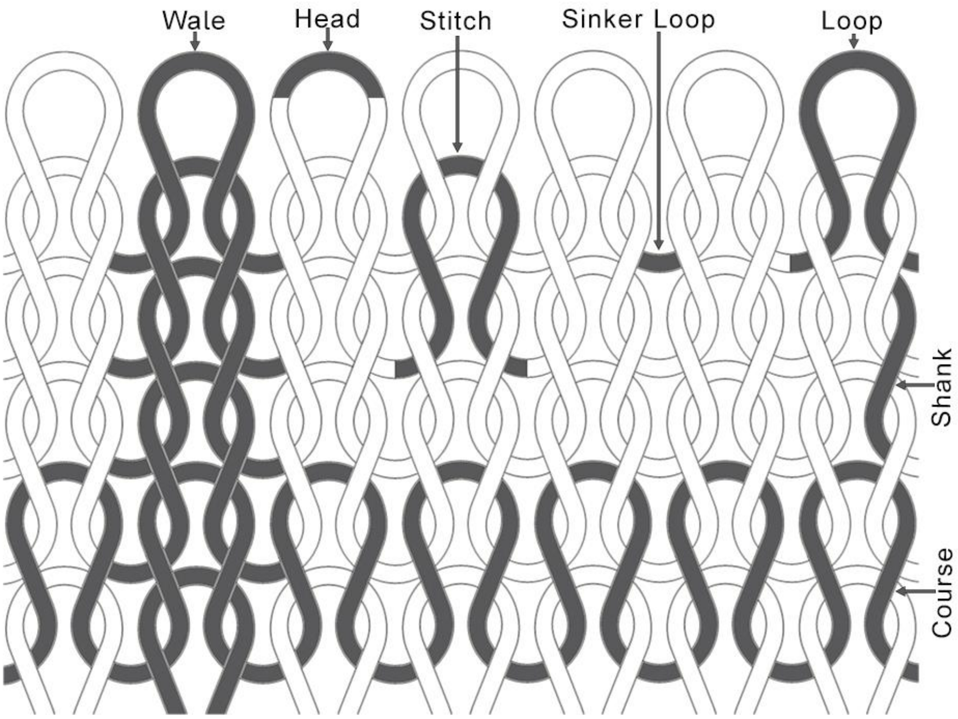


Figure 1.1. Components in a knit fabric

Stitch: though loop and stitch are frequently used interchangeably, stitch has some distinction than the loop. It is the unit of dimensionally stable intermeshing knitted structure and characterized by at least three intermeshing loops (Spencer, 2001i). It is composed of a head, two shanks and two feet or part of sinker loops (Iyer et al., 2004).

Needle loop: loop drawn by needle through the head of old loop is called needle loop. Practically, in weft knitting, all loops are created by needles (Iyer et al., 2004).

Sinker loop: the connection of two adjacent needle loop is called sinker loop. Actually it is the feet of adjacent loops length of which in single jersey fabric is determined by sinker (Iyer et al., 2004).

Course: horizontal row of loops produced by sequential needles is called course. In weft knitting, a course is always produced by a single yarn (Ray, 2012g). Multiple yarn in fed to produce multiple courses during a single rotation of cylinder. Length of yarn consumed by all the active needles during a full rotation of cylinder is called course length (Spencer, 2001g).

Wale: a vertical column of loops in a knit fabric is called a wale. In weft knitting, a wale is always produced by same needle during its knitting cycles. Depending upon the operating cams the needle follows, a wale can be composed of different types of stitches. For this reason, number of wales in a knit fabric is always same to the number of needles in a machine (Spencer, 2001l).

Plain stitch: when the needle reaches such a height that it receives new yarn and knocks off the old loop at every course regularly then the stitch produced is called plain stitch or knit stitch. A fabric cannot be produced without knit stitch. Figure 1.2 shows different types of stitches in a knit fabric (Iyer et al., 2004).

Tuck stitch: when a needle reaches such a height that it can receive new yarn but cannot knock-off its old loop rather knocks off on the next cycle, then the last old loop cleared is called tuck stitch. A tuck stitch is always associated with a held stitch which had not been knocked off before knocking off the tuck (Ray, 2012g).

Float stitch: during knitting cycle, if a needle reaches such a height that it can neither receive new yarn nor it can knock-off its old loop, then the connecting loop created by the preceding and succeeding needle is called float stitch. A float stitch is always associated with a held loop (Spencer, 2001o).

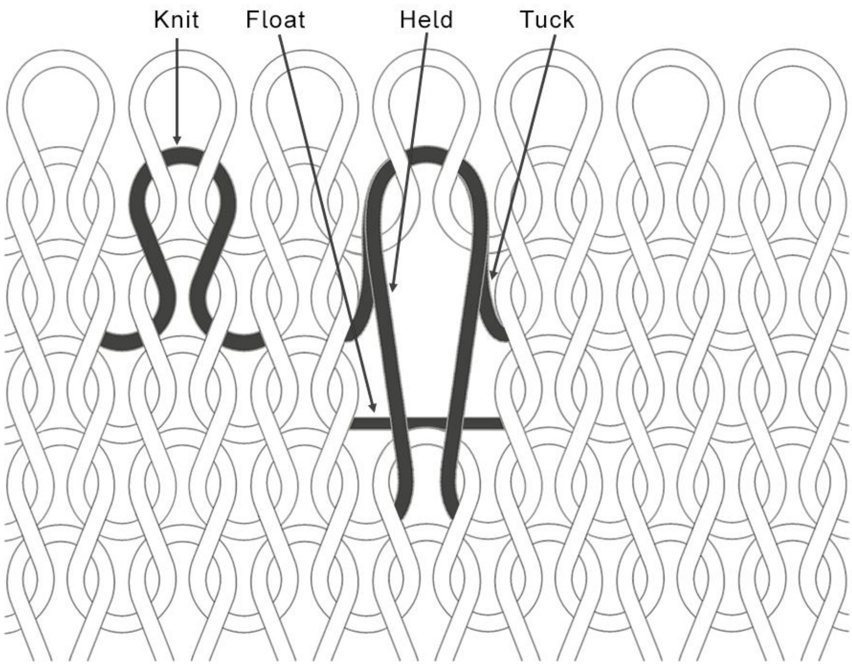


Figure 1.2. Stitch variation in weft knit fabric

Stitch length: stitch length or loop length are interchangeably used. It is the length of yarn that a loop or stitch consumes during its formation. Depending upon the type of stitch or loop combination used in a course, individual stitch length can vary. Therefore, stitch length is always calculated as an average of a number of loops in a course (Ray, 2012g). For larger stitch length, a fabric becomes porous and lighter while for smaller stitch length, it becomes denser and heavier (Spencer, 2001i).

Stitch density: it is the number of loops in unit area of knit fabric generally calculated by multiplying number of courses in unit length and number of wales in unit width (Ray, 2012g).

GSM: the most common term used commercially to attribute a knit fabric is GSM. It is actually the weight in grams of one square meter knit fabric. Since knit fabric is stretchable, the commercial practice for trading it is by weight. Thereby, the GSM explains how denser or heavier a knit fabric is for a given yarn number or count.

Weft and filler: weft and fillers are extra inlaid yarns within a knitted structure. If the inlaid yarn is used parallel to the course, it is called weft where as if the yarn is inserted parallel to the wale, it is called filler. Weft and filler influence the stretchability of knit fabrics along with addition of strength, weight and ornamentation (Iyer et al., 2004).

Plating: plating is used mainly for ornamentation or imparting some special properties in the fabric. Generally, two yarns, different in color, coarseness or other properties are used simultaneously in the same knitting cycle. Depending upon the color used, this type of fabric can show one color on face side and another color on back side of the fabric (Ray, 2012o).

Needles: the primary knitting element in knitting machine is needle which makes a compound movement for producing loops. In circular weft knitting, the needle moves round the machine axis along with the cylinder and at the same time performs an upward and downward movement. Though latch needle is mostly used, bearded and compound needles also have uses in different types of machines (Ray, 2012q).

Sinker: sinker is the second primary knitting element though double jersey knitting machines do not use sinker. It is a specially shaped flat metal plate that sits in between each needle in single jersey knitting machine and warp knitting machine. The sinker helps in loop formation, holding down and knocking over of old loops from needles (Spencer, 2001c).

Machine gauge: it is the expression of the density of needles in a machine. The number of needles in one inch of needle bed is called machine gauge (Ray, 2012q). Higher the gauge, finer is the used yarn or denser is the fabric. General purpose knitwear like Tee shirt or Polo shirt uses 24 to 36-gauge machine. The sweater industry uses up to 18-gauge machine.

Cam: cams are specially designed metal part that gives reciprocating motions to needle and sinker in weft knitting machine, and needle bar and guide bar in warp knitting machine (Spencer, 2001c).

Feeder: the attachment in a knitting machine that represents yarn to needles at an appropriate height and angle is called feeder (Ray, 2012c). The commonly used feeder density is three for a knitting machine in knit factories, above which, the spirality increases though production per hour also increases. Each feeder is associated with a set of cams commonly termed as cam box which defines whether a particular type of needle can receive or not a new yarn from that particular feeder.

1.3. Types of Knitting

Knitting can be classified on the basis of the direction of fabric creation or on the type of machine used (Y Kyosev & Renkens, 2010). Based on the direction of fabric creation, knitting is classified as weft knitting and warp knitting. On the type of machine used, it is again classified as circular knitting, flatbed knitting and straight bar knitting.

1.3.1. Weft Knitting

The knitting process where direction of fabric creation is along the width of the fabric is called weft knitting (Ray, 2012d). This is the most preferred and diverse knitting method for everyday use garments of knit fabric where loops are formed successively by all needles (Alpyildiz et al., 2009; Spencer, 2001g). Weft knitting can further be classified as single jersey or double jersey depending upon number of needle beds used for the production of fabric (Ray, 2012d). Depending upon the type of structure produced, the machine can again be classified as single jersey, rib, interlock and purl knitting (Spencer, 2001q). Figure 1.3 shows basic structural difference between weft knitting and warp knitting.

1.3.1.1. Single Jersey

This type of fabric, also known as jersey fabric is produced on machine either circular or flatbed having or using one set of needles or one needle bed (Ray, 2012b). If the fabric is produced using knit loop only, it is called plain single jersey. If combination of knit, tuck and miss loops are used then the fabric is called single jersey derivative. Most common single jersey derivative we use in our outwear are Single Lacoste, Double Lacoste or Pique. This type of fabric has distinctive face side and back side formed by face loops and back loops. Single jersey fabrics are knitted on preferably sinker top machine with a cylinder offering single needle bed with greater design flexibility but no dial (Spencer, 2001e).

1.3.1.2. Double Jersey

Fabric produced by using two needle beds irrespective of circular or flatbed machine is called double jersey fabric (Ray, 2012g). This type of fabric can further be classified as rib, interlock or purl.

Rib: the fabric produced by two sets of needles where the needles are arranged in alternative manner so that they can operate in between each other without touching when raised, and face wales and back wales can be knitted on each side of the fabric is called rib fabric (Ray, 2012b). This type of fabrics is characterized by cord like appearance on both sides, higher stretchability in width direction and balanced energy level (Spencer, 2001q).

Interlock: interlock is also produced on double bed knitting machine but the difference with rib is, the needles are arranged face-to-face (Ray, 2012b). To avoid needle collision from both beds, two types of needles are used namely short needle and long needle. Therefore, the cam system is also different from rib, the rib machine can operate with only one track in cam in each bed but the interlock requires at least two tracks in each bed. Due to face-to-face position of needles, the loops produced on face side sit directly opposite to the loops in the back side (Spencer, 2001q). A plain interlock thereby has same appearance like plain single jersey on both the technical face and technical back side of the fabric. This type of fabric is thicker, heavier than single jersey with same yarn count and gauge.

Purl: purl fabric is also produced on double bed knitting machine but uses only one set of needles with double head. The needle, essentially double headed latch needle, moves from one bed to other and creates fabric with respective head. That is why, a single wale in purl fabric can show both the face loop and back loop on each side of the fabric (Ray, 2012b).

1.3.2. Warp Knitting

The technical basis for warp knitting technology is supposed to be founded in 1589 (Ray, 2012p). Warp knitting as shown in Figure 1.3 differs in the direction of the progression of fabric creation. In weft knitting, a yarn moves along the width of the fabric while knitting but in warp knitting, the yarn moves along the length of the fabric sequentially looping after looping (Ray, 2012d). At least a set of yarn is required to feed the needles and the needle movement is collective and fixed on needle bar (Spencer, 2001g). Therefore, the needles on a bar always have identical lapping or loop formation in a particular course (Spencer, 2001d). Yarns are presented to needles by guides collectively fixed on guide bars which performs compound lapping movement by swinging and shogging motion generated by cam system (Ray, 2012k). The fabrics are comparatively less stretchable than weft knit fabric and most of the fabric shows curling tendency. Most common types of machine for warp knitting are Tricot, Raschel, Simplex and Milanese where Tricot and Raschel machine can have either one or two needle beds (Gajjar, 2011). Warp knitted fabrics have wide uses in technical application while weft knitted fabrics are mostly used in everyday domestic use and as apparel or garments (X. Chen & Hearle, 2010).

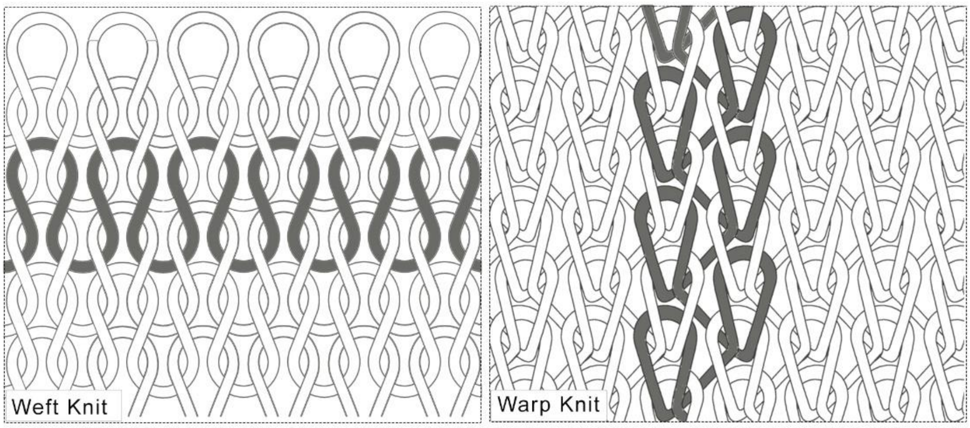


Figure 1.3. Difference between weft knit and warp knit

Other than the above-mentioned terminology for classification of knitting, there are some other classifications like circular knitting, flatbed knitting and straight bar knitting. Circular knitting machine offers higher production speed with either single cylinder for one needle bed or a cylinder and dial for two needle beds where needles rotate with the rotation of cylinder and dial (Au, 2011). The produced fabric is mainly tubular though extra attachment can be used to convert the fabric open width. This type of fabric is mainly used for cut and sew method for garment production (Spencer, 2001s). Flatbed machine as the name indicates are long in shape and widely known version is V-bed rib machine used for collar and cuff (Spencer, 2001j) though tubular fabric can also be made (Boakye et al., 2018). Modern version of this type of machine offered by Shima Seiki (ShimaSeiki, 2021) and Stoll (Karl Mayer, n.d.) can produce fully fashioned garments. Another version of this machine is purl or link-link machine. Straight bar is renowned for its development in fully fashioned seamless production (Spencer, 2001r) where garments sequence can be programmed and the machine can initiate required alteration for producing garment length construction instead of continuous fabric (Spencer, 2001s). This type of machine is widely used for hosiery, legwear, internal wear and gloves production.

1.4. Uses of Knit Fabric

Single jersey fabric gained its popularity mainly after the fashion trend for printed fine-gauge lightweight fabrics starting from 1973. Double jersey fabrics are preferred to single jersey for ladies wear since single jersey fabric, if not properly finished used to show dimensional instability and structural breakdown (Spencer, 2001e). Other than these basic structures, there are specialty knit fabrics like fleecy, plush or pile, double sided plush and sliver or high pile fabric which have found uses in everyday life like garments and in households (Spencer, 2001n). Besides the general uses as clothing, as an alternative to woven and nonwovens (Spencer, 2001p), knit fabrics are also being used in as industrial textiles, medical textiles, orthopedic garments, automotive textiles, agro textiles and geo textiles (Au, 2011; Ray, 2012m, 2012f). Noticeable uses of knit fabrics are also being found in sound absorption materials (Monaragala, 2011) and in complex geometrical composites due to their excellent formability (Alpyildiz et al., 2009).

Global market size for knit fabric was USD 23.8 billion in 2018 (Grand View Research, 2022) which reached USD 24 billion in 2020. According to the Fact.MR's report, it will increase at a CAGR of nearly 5% from 2021 and will reach USD 40 billion by 2031 (FactMR, 2022). Weft knit fabrics are supposed to dominate the share and the driving forces behind this growth summarized by the report are its low cost and easier manufacturing method. Knit fabric shows better breathability, lightweight and wrinkle resistance which are making it preferrable to others. As consumer preference is shifting towards wrinkle resistant, flexible and comfortable garments, knit fabric is steadily growing in denim garments. Besides, the uses of knit fabrics in automobiles, construction, manufacturing and medical sectors are some of the scopes that would fuel the market demand over the forecast period (Grand View Research, 2022).

1.5. The Costing Systems

The global market has reached a point of extreme competition, and automation, technology, and computerization have all played a role in this by moving costs from labor-intensive to capital-intensive. As a result, the cost profile is rapidly being dominated by administrative costs rather than direct material and labor costs (Barfield et al., 2002). Without improvements in organizational administration systems, of which the management accounting system is one component, technological advancements alone will not enough (Schoch et al., 1994). Despite their advantages of high automation, flexibility, and high-quality items, these systems will be unable to compete without a realistic and more exact costing mechanism (Rezaie et al., 2008) where they must know the exact cost of a product they produce (Değirmenci & Çelik, 2013).

1.5.1. What is Costing

Cost is described as a sacrifice made, evaluated by the worth of the resources given up to achieve a specific aim (Polimeni, 1999), and is likely the most influential factor in the outcome of a product or service in many of today's businesses (Caprace & Rigo, 2012). It is still a challenging exercise in current globalization that, in order to ensure long-term sustainability, the costing system properly ensures that the company's offered products or services do not lose their competitiveness due to illogical market prices (Siguenza-Guzman et al., 2013). To do so, they must continuously improve their processes by describing how the many operations inside the organization are developed in order to boost efficiency and effectiveness, resulting in more competitive and higher-quality products and services (Almeida & Cunha, 2017). In the first half of the nineteenth century, the first systematic costing procedures were created with the intention to record costs incurred during the manufacturing process in order to identify cost-cutting opportunities. Direct labor costs and material costs were the main concerns because both were variable. since non-variable costs could not be changed, they were regarded irrelevant in any judgments. The overall cost of a product is then estimated by allocating total overhead as a proportion of direct labor to each product (Hergeth, 1996). With the changing world, it was realized that, among other things, selling materials in standard dimensions, the excessive variety and complexity of material assortment, ordering, transporting and the intertwined financial means result in significant costs (Więcek et al., 2020). As a result, it was realized that costing be based on three primary factors that are universal to all businesses and can be summarized as Wages, Materials, and Overhead Charges (Broadley, 1944) and activities attached to raw material accumulation, production, distribution, after sales service should be accurately and numerically valued to costing which founded the idea of Activity Based Costing (Vinodh et al., 2009). Several other costing concepts also emerged and practiced in full or partial scale in different organizations; some of which have been mentioned bellow.

1.5.2. Types of Costing System

Traditional Costing System: this costing system was based on simple principle where raw material cost and direct labor costs are directly attributed to product. Indirect costs are distributed depending upon a cost driver that are generally characterized by the proportion of direct labor or machine hour or units of output. With the use of more and more automation in production system, the weight impact of direct cost relatively decreased in comparison with the indirect cost and this costing system may produce distortion signal if the cost driver depends on volume only and thereby regarded to be unable to estimate adequate cost information for most organization (Siguenza-Guzman et al., 2013).

Job Costing: when units of final output is not high in number but each unit is different in nature and engages different amounts of resources (Horngren et al., 2010) in completing a unit, job costing is thought to be more suitable. A job can be a product or service easily distinguishable from other products or services such as a construction project to build a house from beginning to end or building a custom aircraft or construction of a new rail road. The overall concept here is that the product or service is a one-time event and little expected to match fully with previous product or service. This system records costs and revenues for each individual constituent jobs, accumulates those and finally attach to the end product or service (Lanen et al., 2016).

Process-Based Costing (PBC): Process costing does not separate and record costs for each unit (Lanen et al., 2016) rather it is used for mass-production settings. It first analyzes the net cost of a section of a manufacturing process over a specified period. The cost incurred during this period is then divided by the unit of product produced or service delivered and considered as standard cost for that particular section. Manufacturing plant that requires more than one step proceeds similar calculation for each step and accumulates to cover entire production system. Since the unit cost of a product or service is calculated by assigning total cost to many units of output (Horngren et al., 2010) thereby it is basically an average cost per unit (Barfield et al., 2002) system which depends on process flowchart but doesn't really fit to calculate service cost (Azevedo & Sholiha, 2015).

Operation Costing: Many companies use a hybrid costing system merging process costing and job costing to suitable extent and term it as operation costing. It actually combines the aspect of job costing to assign materials separately and aspect of process costing to assign conversion costs equally to each operation. This type of costing model is preferred where various product lines have different direct materials but nearly similar processing techniques (Barfield et al., 2002).

Activity Based Costing (ABC): ABC, developed by Robin Cooper and Robert Kaplan (Doyle, 2002), on the other hand accumulates all the indirect costs; breaks down or decomposes total main and supporting functions of an organization and recognizes separately as unique entities (Alami & ElMaraghy, 2020; Kaiser, 2019). In other words, the thing a person does in a firm like designing products, setting up machines, operating machines, and distributing products are all entities or activities (Horngren et al., 2010) in this concept. These activities are assigned with costs depending upon usage of resources and relevancy. Activities those are valued by same cost driver are then grouped or pooled (Jiambalvo, 2003). Finally with a principle that product or service consumes activity, they are assigned to products or services depending upon the relative consumption (Bufi, 2014; Goddard & Ooi, 1998) and thereby final cost of the products or services are determined based on the activities consumed to produce, perform, distribute, or support those products and services (Barfield et al., 2002; Go & Weng, 2021). Although some researchers believe that with the increasing number of cost pools, the ABC systems can increase cost measurement errors (Ittner et al., 2002) but most of the researchers opines that based on activity analysis this system can provide more accurate product or service costs (Duh et al., 2009). However in manual accounting and cost management system it may appear difficult to implement this approach and may appear time consuming and very complicated (Azevedo & Sholiha, 2015) to update and compile into decision making information.

1.6. Application of Computer in Textiles

An important factor in the rapid development of this industry is computer technology (Hu, 2011), which reduced the amount of manual labor while also ensuring precision and certainty (Deb, 2011). New York-based IMB introduced the world's first computerized textile design system in 1967 which was able to process technical production data of jacquard weaving (Ujiie, 2011). Artificial intelligence, machine vision, image processing and pattern recognition, human interaction with computers have made significant progress since the 1980s, and machine manufacturers have begun integrating these technologies into their machines to improve textile industry standards and replace the subjective human evaluation methods that were previously used (Baciu & Liang, 2011; Xin et al., 2011). Continuous academic collaboration between textile and computer scientists, expanded capabilities with powerful algorithms, and a dramatic drop in computer prices have given computer technology in the textile industry more support and accelerated its adoption (Hu, 2011).

In the yarn manufacturing process, there are numerous procedures that must be completed, such as opening, cleaning, carding, drawing, combing, and spinning (Chattopadhyay, 2011). Predicting the characteristics of yarn based on the qualities of the raw materials and the production conditions is a typical procedure. In other words, yarn engineering refers to the process of determining which materials and procedures should be used to produce a yarn that meets the predetermined quality standards while still remaining within a reasonable price range (Basu, 2011). Therefore, to include the relative importance of fiber properties for the prediction of yarn performance (Guha, 2011), different computer algorithms and artificial intelligence tools (Murugananth, 2011) have been adopted in the yarn manufacturing systems (Ognjanovic, 2010). It is now common practice in the manufacturing line to employ computer algorithms to analyze fiber grading (Sarkar, 2011), yarn modeling (Majumdar, 2011), yarn engineering (Basu, 2011) and property modeling (Chattopadhyay, 2011), filaments drafting (Jungbecker & Veit, 2012), identifying and classifying yarn evenness, hairiness, twist, and snarling (Xu, 2011), false-twist modeling in texturing yarn (Veit, 2012b).

Unique characteristics such as flexibility, wearability, aesthetic quality, sewability (Xin et al., 2011), strong resistance to stretch but weak resistance to bend make a fabric distinct from other sheet materials (Wong, 2011). As well as being produced in the traditional sheet form, fabrics can also be made to include the necessary features in the third dimension (Nazarboland et al., 2010). Fabrics can be manufactured by traditional weaving or knitting from yarns or directly from fiber assemblies as nonwovens (Mao & Russell, 2010). The type of manufacturing method, the fiber, the fineness and evenness of the yarn, the tightness of the fabric, and the dimensional stability of the finished fabric all play a role in fabric quality and serviceability (Blaga, 2011). When it comes to designing fabric for aesthetic purposes, there has been a long history of trial and error (Behera, 2011). Other than the process and parameter optimization for commercial benefit, for technical applications, precise prediction of performance and serviceability is required. Therefore, computer technology has made its way in the fabrication unit in the form of parameter optimization and prediction, machine optimization and visual simulation of fabrics. Modeling fabric structures (Baciu et al., 2011), identifying weave patterns (Xin et al., 2011), defect analysis, and classification (Kumar, 2011), fabric engineering (Behera, 2011), quality evaluation (Merati & Semnani, 2011), modeling thermal properties (Kothari & Bhattacharjee, 2011), modelling of tearing strength (Witkowska & Frydrych, 2011), behavior modelling of textiles (X. Chen & Hearle, 2010), deformation analysis (Vidal-Salle & Boisse, 2010), modelling of filtration property (Nazarboland et al., 2010), elasticity (Volino & Magnenat-Thalmann, 2000a), spirality of cotton fabrics, (Veit, 2012d) carpet pattern design (Veit, 2012a), engineering nonwovens (Patanaik & Anandjiwala, 2011) and composites (Mukhopadhyay, 2011) are some of the integration of computer technology for prediction and parameter optimization in the fabric. Instead of drawing designs on graph paper and doing manual calculations for things like weave and knit drafting, designers now use computers to develop their concepts from scratch (Ujiie, 2011). In addition to converting design to loom instruction for automated lifting plan and weft replenishment, software like Nedgraphics (Anonymous, 2022c), Pointcarre (Anonymous, 2022d), Penelope (Anonymous, 2019), Textronic (Anonymous, 2021) and Arahne (Anonymous, 2022b) offer additional opportunities for pattern generation and rendering (Baciu et al., 2011), weave editing, color matching, avoiding costly mistakes, early stage virtual sampling and pre-visualization of the final fabric without weaving a single pick in the real loom (Redmore, 2011). The widespread use of computerized knitting machines in the textile industry has made knitting easier than ever before (Narayanan et al., 2018). Shima Seiki in 1995 came up with their ‘whole garment’ technology (E. J. Power, 2018) followed by Stoll GmbH with ‘knit and wear’ technology (Blaga, 2011). In today's electronic V-bed flat knitting machines, a CAD/CAM system provides comprehensive patterning and garment shaping capabilities (Spencer, 2001h) for as many design variations as desired while also maximizing the knitting machine's capabilities.

Computer-aided design (CAD) technology and its integration into the apparel industry have reduced product development costs and accelerated the design cycle (Hu, 2011). Textile designers can now create and show virtual samples on a computer screen without wasting materials or manufacturing processes, as opposed to the traditional model of sewing 2D patterns to predict a garment's 3D configuration (Y. Zhong, 2011). Using this technology, 3D modeling can be used to unwrap 2D patterns and simulate draping, as well as to create 3D garments from 2D patterns (A. S. M. Sayem, 2017). Production lines can now review and evaluate fit in virtual reality with realistic simulated fabric behavior, as well as quickly detect and correct design flaws (A. Sayem et al., 2015). Today a number of such systems like Vstitcher (Browzwear) (Browzwear, 2021), Modaris 3D (Lectra) (Lectra, 2022b), TUKA3D (Tukatech) (Tukatech, 2021), 3D Runway (OptiTex) (OPTITEX, 2021), AccuMark 3D (Gerber) (Lectra, 2022a) and Vidya (Assyst-Bullmer) (Assyst, 2022), Marvelous Designer (Marvelous, 2022b), CLO-3D (Marvelous, 2022a), Grafis (Grafis, 2022) and Audaces (Audaces, 2019) are available in the market, many of which offering pattern unwrapping facility (A. S. M. Sayem et al., 2014) for use in the apparel industry. Industry 4.0 calls for manufacturing to be both automated and customized (Anonymous, 2022a; SCOTT & SAYEM, 2018), with designers, manufacturers, and retailers all able to communicate online (A. S. M. Sayem et al., 2010). Demands for developing methods of constructing and simulating garments (Ng, 2011) with more complex structure or texture with realistic simulations (Han & Stylios, 2010) continuously driving innovation further like 3D body scanning and avatar formation (Faust & Carrier, 2011). That is why, though rather costly, 3D CAD systems are becoming increasingly popular in the apparel industry (Istook et al., 2011).

1.7. Product Development: Traditional vs Computerized

Our lives and cultures have been profoundly affected by the garment industry, which has used shape, color and construction to convey a variety of messages in the society about fashion and lifestyle we belong (Baciu & Liang, 2011). For each season, there is a set of high-fashion colors, so-called "transient" that can help define the look and feel (King, 2011). Therefore, fashion industries feel compelled to produce new designs, structures, textures, and blends at a competitive price and without wasting a lot of time in today's competitive and dynamic textile market (Ray, 2012a). Success in fashion relies heavily on originality and imagination. For a new garment, designers start with an idea generation process known as "concept generation," in which they combine physical, medical, economic, social, cultural and religious aspects of target population. To express their initial virtual view, designers typically use sketches either on paper or on computer screen. Sketches of various views of the garment termed as primary sketch give the next person involved in the design process the information they need to proceed (Ujiie, 2011).

This primary sketch, created with pencil and paper, is the traditional starting point for product development (Ray, 2012a). Designers or design technicians then process the sketch for further realistic illustration and preparation of color sets if the design is deemed commercially viable (Behera, 2011). There are a lot of drafts needed by traditional fashion designers in order to achieve an ideal style (Chang & Wang, 1996). Material is selected for primary sampling based on costing if the concept and color set have been approved by the approval body. It is common for existing traditional product development systems to produce two to ten physical prototypes before beginning production for decision making on product selection (A. Sayem et al., 2015). In Gray's reports that, more than seven out of ten real samples (prototypes) are generally rejected from further development after real time assessment which incurs a lengthy and expensive sampling process (Gray, 1998).

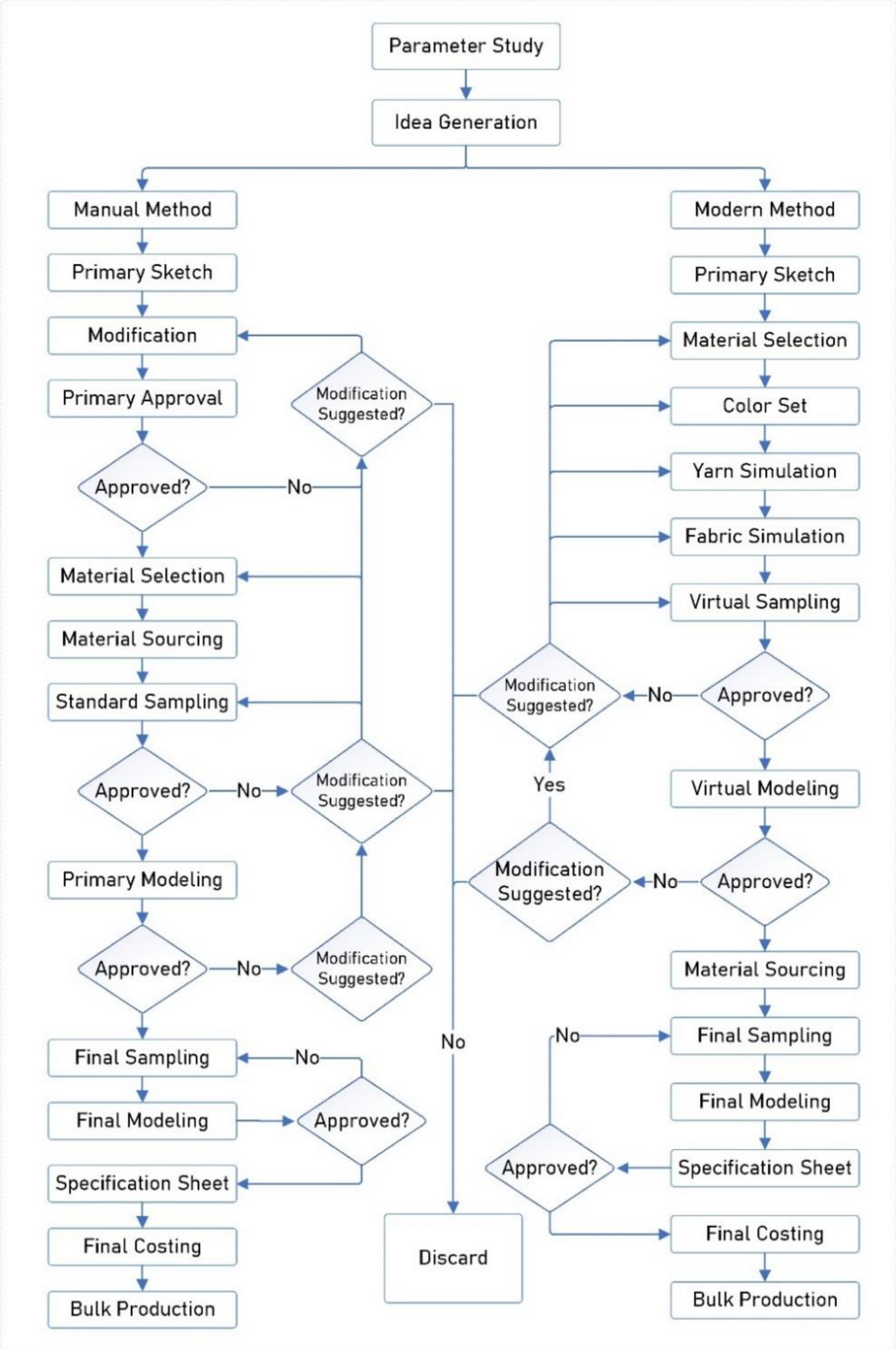


Figure 1.4. Fashion development steps: traditional vs modern

After the approval of prototype, the final sample is made, usually with full color set and in actual size set ready to wear. Inhouse models that wear these sample garments and a cat walk is arranged where jury assess the potential of the product in real life. Depending upon the opinion from jury, the sample can again go for further modification. When finally approved, the detail specification including fiber type, yarn type, fabric structure, color set, size set, garments' geometry is then prepared for bulk production. a comparative view of traditional and modern process of apparel manufacturing can be seen in Figure 1.4.

Designing for fashion is made easier by fashion CAD, a tool that helps fashion designers turn their creative fashion concepts into visuals for use in further illustration processes. Throughout the ages, computer technology has revolutionized the way textile designers approach their work (Ujiie, 2011). In the fashion industry, the evolution of fashion CAD from basic shape modeling to the modeling of complex physics and behaviors, realistic cloth modeling, virtual modeling of garments with appropriate object, environment, and animation, has opened new development phases (Volino & Magnenat-Thalmann, 2000a). For the apparel industry, cloth simulation could be a game changer. With no need for labor-intensive manual tasks like measuring, cutting, and sewing, the prototyping phase is simplified by visualizing an item of clothing without having to make it (Volino & Magnenat-Thalmann, 2000b). Because virtual prototyping eliminates the need for as many physical prototypes, the time it takes to bring a product to market is reduced (A. Sayem et al., 2015). Fashion designers can easily create garments with a wide range of patterns and fabrics using a CAD system (Wong, 2011). There are many advantages to designing products on a computer, including the ability to identify errors before physical samples are produced, and making design revisions before physical samples are produced (Lamar, 2011). Therefore, modern fashion development procedure differs a lot from the traditional ones as shown in Figure 1.4. In modern system, the real sample is prepared after full scale virtual modeling in the computer. If the concept is approved then the real sample is prepared and again a real modeling is performed. Thus, the development cost and time for a new idea are saved and the company can respond to market demand quickly. Again, a quick response and the marketing of standard products are not enough for the clothing industry without satisfying young customers by developing product differentiation. Consumers' retail experiences and their perceptions of a good fit, in addition to style, price, and garment construction, are now seen as important differentiators in the apparel industry (Faust & Carrier, 2011). As a result, apparel business sector is implementing new business strategies and adopting new technology (Metaaphanon & Kanongchaiyos, 2005) for its sustainability. There are a number of strategies, such as mass customization and fast fashion, that rely on flexibility, even to the point of delivering one-of-a-kind products, speed in apparel design and development (Lamar, 2011) and virtual presentation in the global information medium (Luchev et al., 2013).

2. LITERATURE REVIEW

2.1. Scope of Activity Based Costing

Material handling, warehousing, different types of maintenance jobs, engineering works, setup, depreciation, utility support, quality control, customer relations, after sales service etc. are considered as overhead costs (Fernandes et al., 1997). The traditional costing systems were designed to meet the needs of production enterprises with higher labor costs that could significantly influence managerial decisions. It was supposed to calculate total raw material cost and direct labor cost and add up overhead cost with an arbitrary proportion, in most cases on the proportion of direct labor costs (Rezaie et al., 2008). In the current competitive environment aspects of indirect costs have increased dramatically and, in some cases, even surpasses direct labor's cost. Therefore, traditional costing systems these days not only may provide inaccurate and distorted cost information but also misrepresent manufacturing efficiency and effectiveness (Koltai et al., 2000; Tippett & Hoekstra, 1993). ABC model is believed to fit in small (BHARARA & LEE, 1996) to multilevel complex scenario (Raab et al., 2007), capable of considering cost generating activities and mapping them to respective products for final costing (Valderrama & Sanchez, 2006). Its overhead allocation is based on exact knowledge (Koltai et al., 2000) of the resource consumption and thereby supposed to give more accurate cost information (Fichman & Kemerer, 2002; Park & Simpson, 2008; Rezaie et al., 2008) by accepting participating activities but removing irrelevant ones (Suthummanon et al., 2011).

Activity Based Costing system has been recognized by many researchers (Kissa et al., 2019) and adopted successfully by many manufacturing industries over the last three decades with positive outcomes (Raab & Mayer, 2004). Dekker and Van Goor studied impact of ABC on supply chain management (Dekker & Van Goor, 2000), Manunen applied ABC for estimating logistics cost (Manunen, 2000), Doyle studied ABC in database marketing (Doyle, 2002), Nachtmann and Al-Rifai applied ABC in AIRCO (Nachtmann & Al-Rifai, 2004), Raab et al. applied ABC in a Hong Kong Buffet Restaurant (Raab et al., 2005), Raab, Shoemaker, and Mayer tested ABC model in a restaurant operation in a western urban area of the United States (Raab et al., 2007), Yen-Ju Lin et al. studied role of ABC on health care system (Yen-Ju Lin et al., 2007), Annaraud, Raab, and Schrock applied ABC in Quick Service Restaurant (QSR) (Annaraud et al., 2008), Suthummanon et al. applied ABC on parawood furniture factory (Suthummanon et al., 2011), Zhuang and Chang developed a model based on ABC to identify optimum product mix (Zhuang & Chang, 2017), Lu et al. studied ABC against volume based costing (Lu et al., 2017), Yang studied impact of ABC on green power suppliers to more accurately understand optimum resource and funding allocation (Yang, 2018), Defourny et al. applied ABC to isolate costing of beam radiotherapy (Defourny et al., 2019), da Silva Etges et al. studied time driven ABC in health organization for accurate micro costing analysis (da Silva Etges et al., 2019), Shankar et al. studied time driven ABC on Oral Contrast Administration in the Emergency Department (Shankar et al., 2019), W.-H. Tsai and Jhong studied ABC on knitted footwear industry (W.-H. Tsai & Jhong, 2019), Reveco et al. used ABC for determining operating cost of medical surveillance program for copper miners (Reveco et al., 2019), Araújo et al. applied ABC in agroforestry (Araújo et al., 2020), Duran and Afonso proposed ABC for to manage critical non-repairable spare parts inventories (Duran & Afonso, 2020), Parikh et al. studied time driven ABC for delivering Stereotactic radiosurgery (SRS) (Parikh et al., 2020), Hauser et al. applied ABC in an interventional radiology practice department (Hauser et al., 2020), Mericli et al. applied ABC in microvascular breast reconstruction department (Mericli et al., 2020), Masthoff et al. studied impact of ABC in interventional radiology section (Masthoff et al., 2021) – to mention a few of many.

2.2. Costing in Knitting

There are many developing and developed countries that depend on textile and apparel manufacturing and trade, and this is especially true in Asia, where textile and apparel manufacturing and trade is a major industry for employment, export revenue, and GDP (W. Chen et al., 2017). In terms of the Turkish economy, textiles and clothing play a critical role in terms of GDP contribution which made up 17.2% of all exports in 2019. with 2.70 percent of the global clothing market share, Turkey's clothing industry ranks 7th worldwide and 3rd in the EU. It is the 6th largest exporter of knitted clothing in the world, with a market share of 3.80%. A shift from low-value commodities to high-value manufactured and fashionable goods took place in the industry gradually from 1980 - 2018 (Directorate General of Exports, 2021). A major shift in the textiles from labor-intensive to a capital-intensive industry occurred because of technological advancements that lowered the direct labor costs. Again, a large variety of styles and products is common in most textile mills and this variety causes different costs (Hergeth, 1996) which justifies adoption of a costing system that can predict and forecast company’s sustainability and competitiveness.

The success of the cost model depends on objectives, simplicity, availability of computer-based system, culture of the implementation environment and most importantly properly defined cost-allocation driver. A cost-allocation driver often referred to as cost-allocation base links the costs incurred with the products or service (Jiambalvo, 2003). In each cost model it’s a matter of great concern to determine which cost-allocation base perfectly fits and proportionally reflects the link for cost distribution and how many cost-allocation bases should be enough to avoid unwanted complexity. In the past, many manufacturing-oriented organizations preferred to use direct labor as the only cost driver but in modern days of automation, it came out to not be able to reflect and distribute cost to product relation properly. Some organization preferred to use machine hours as cost driver but it also failed to reflect the cause-effect criterion properly. The revision of costing models are thereby encouraged by this cause-effect relation and since manufacturing companies uses various types of resources like people, facilities, utilities; modern cost models suggest to use multiple cost driver like time, machine hour, space, utility ratio respectively (W. H. Tsai, 1996). In the implementation case the real scenario is that every company has its own unique costing methods that do not precisely fit any textbook description (Lanen et al., 2016).

A study by Rendall et al. looked into how textile companies currently price their products and manage their costs. They found that textile companies predominantly use traditional costing system leaving rooms for improvement required by current competitive market. They suggested that existing costing system need to be corrected or replaced by modern cost management practices like activity-based costing system which can help them gain a better understanding of the root causes of their high overhead costs (Rendall et al., 1999). The nature of textile companies is different, some of them are composite, some of them are partially composite while some of them are with single unit with low investment and knitting factories fall in mentioned three categories. It can be part of fully composite, or partially composite but most of the knitting factories are unique identity who collects yarn, produce knit fabric and send to another identity. In this sense, a unique establishment type knitting factory is a very small company with lower financial capacity. This type of small enterprises can’t afford highly reputed costing software like SAP offered commercially in the market which make them bound to practice traditional or self-justified partially modified traditional costing system. Therefore, for the sake of textile field, a convenient costing system developed taking all necessary technical parameters in knitting sector is still to be addressed and this has been the first motivation of this research.

2.3. Knitting Geometry

Textiles are nothing but composition of fibers, the final product inherits many of its properties from fiber's physical and chemical properties (Grishanov, 2010) which can’t be altered without extensive physical or chemical treatments.

Structures knitted from loops have a higher porosity and greater extensibility than other types of textiles (Pavko-Cuden et al., 2013; Wadekar et al., 2020). Therefore, Other than the inherited fiber property, macroscopic behavior of knitted fabrics is more dependent on their loop structure, stitch patterns and mechanical interactions at the yarn level (Cirio et al., 2017; Wadekar et al., 2020). Weft knitted fabrics have a wide range of geometrical configurations at loop level, and these again can vary according to the fiber and yarn properties.

The way a knitted structure behaves is determined by the length and shape of the loops that make up the structure. Loops embed in a complex 3D configuration (Castillo et al., 2019), and the length is mostly determined by the machine during loop formation (Ray, 2012j). Combination of loops in the form of a course affects fabric dimensions and other properties, such as unit weight or GSM (Spencer, 2001b). Although the loop shape is determined by the yarn used and the treatment given to the fabric (Ray, 2012n), it is finalized after the fabric has been relaxed (Ray, 2012i). It is important to note that the dimension of a knitted fabric is influenced by both the shape of the individual loops and how they embed together (Hepworth & Leaf, 1976). Therefore, Knitting loop geometry has come out to be the key element in understanding the dimensional behavior of knitted fabrics (Yordan Kyosev et al., 2005) and understanding the loop geometry and mechanism of loop formation is believed to optimize machine, process, and yarn parameters to produce desired knit fabric (Ray, 2012i).

Knitted structures have been studied extensively and several models have been proposed by quite a number of academics (Kurbak & Ekmen, 2008). The models began by making an assumption about the geometrical loop shape and then adjusting various parameters until the model better fit with the experimental results (Semnani et al., 2003; Shanahan & Postle, 1970). It was assumed in the models that the loop was symmetric, with a circular cross-section and throughout uniformity of the yarn (Yinglin et al., 2014).

Dutton (Postle, 1968) is believed to be the first to study the dimensional properties of knit fabrics extensively though Chamberlain used circular arcs and straight lines to create the first 2-D geometric model of a plain-knit structure in order to investigate relationships between fabric dimensions (Leaf, 1960), which Shinn investigated in more depth (Shinn, 1955). Academics pointed out two limitations in this model in terms of third dimension due to interlacing and length of yarn in the stitch (Demiroz & Dias, 2000a). It was Peirce who extended the Chamberlain model to include a third dimension by using generators that ran perpendicular to the course axis (F.T. Peirce, 1947; Frederick Thomas Peirce, 1937). In his model for weft knit fabric, he proposed a minimum wale spacing of four times and a course spacing of $2\sqrt{3}$ times the yarn diameter (X. Chen & Hearle, 2010). Leaf and Glaskin, among others, pointed out that the assumption of torsion or twist of the yarn during bending into the shape in this model was flawed (Leaf & Glaskin, 1955) and that a stable fabric could not be made from loop shape proposed by Peirce (Leaf, 1960). For more accurate estimations, Leaf et al. (Leaf, 1961) proposed four symmetrical space arcs (Wadekar et al., 2020) to define the loop shape. They assumed that yarns are elastic, and the elastic property governs the bending of yarns during the formation of loops (X. Chen & Hearle, 2010). While the model's simplicity and good depiction of the actual fabric make it a hit (Choi & Lo, 2003), its foundation remains in 2-dimensional models (Sha et al., 2021). Doyle focused on the load-extension properties of plain fabric considering stitch length to be the most important factor (HURD & Doyle, 1953). He tried to link the properties of a knit fabric to the yarn's flexural, torsional, and inter-yarn frictional properties (Walker & Doyle, 1952). While Munden and Doyle both agreed that relaxed plain-knit fabrics' dimensions are entirely determined by the stitch length (Postle & Munden, 1967).

Almost all researchers agree that the stitch length or loop is the fundamental parameter governing the majority of fabric properties (Ajeli et al., 2009), which predominantly influences the dimensional stability of knit fabric with other parameters like fiber characteristics, machine gauge, yarn twist, knitting tension, and washing and drying methods (Moon Won Suh, 1967). Relaxation state of a fabric is defined as a condition where the fabric is in its strain-free state (Munden, 1959). Munden assumed that the path of an yarn was in a minimum energy configuration when the fabric was in fully relaxed condition (Wadekar et al., 2020). In contrast to wet-relaxation shrinkage, Postle Model pointed out that synthetic fabrics shrink more and change loop shape more when tumble dried at higher temperatures. For all the fabrics, he proposed a wet treatment with elevated temperature to bring them into complete relaxation and achieve the same loop configuration (Postle, 1969). In light of an energy analysis and the inadequacy of classic k-values, K. F. Choi proposed a new model involving the natural curvature of the yarn in the fabric which shows a good compatibility for a plain-knit in terms of its dimension and low-stress mechanical properties. Fong model presents a new geometric explanation and numerical analysis approach for laid-in weft knitted fabrics with complex inter-looping layout (Fong et al., 2021).

The traditional definition of loop shape factor is based on parameters such as tightness factor and machine gauge, as well as yarn linear density though this shape factor value is not a true representation of loop shape (Banerjee & Alaiban, 1988). Again, the tensile properties of yarn, including others originating from fibers, combine with the structural behavior of knitted fabric to produce its mechanical behavior (Htoo et al., 2017). Numerous studies have been conducted to correlate these properties with knit fabrics, in addition to the proposed geometric models. These studies include the effect of friction between the yarn and metal (Nutting, 1960), yarn input tension (Aisaka et al., 1969), cam setting (Knapton & Munden, 1966; Munden, 1960b), cam shape (Black & Munden, 1970; Henshaw, 1968), fabric take-down load and yarn properties on loop length (Munden, 1960a; Oinuma, 1989), and yarn tension within the knitting zone (PIETIKAINEN, 1981; Ray & Banerjee, 2012). Earlier mechanical analyses and modeling of knitted-loop shape's three-dimensional nature usually ended up to a mathematical complexity and complicated geometrical interpretation of the fabric structure (de Jong & Postle, 1977a) leading to inexplicable difficulties to compare theoretical and experimental values of fabric dimensional parameters (de Jong & Postle, 1977b).

To explain the properties of knitted structures, the models proposed so far are still inadequate comparing to the woven fabrics' models (Cirio et al., 2017). Again, for the most part, the models proposed are based on plain knits or single jerseys (Pavko Čuden, 2010), with little consideration given to the double jersey, such as rib (Kurbak, 2009) or interlock (Jeddi & Dabiryan, 2008). This lack is often attributed to the complex nature of intermeshing in 3D space, variable properties of fiber, yarn and fabric due to natural and manufacturing parameters. It is very true that, there is still no universal mathematical framework that can accommodate these ever-changing configurations satisfactorily (Nutting & Leaf, 1964) without accepting uncertainty and large tolerance in errors (Frederick Thomas Peirce, 1937).

2.4. Fashion and Design in Knit Fabric

Global clothing market was estimated to bring in $1,803 billion in 2019 with a forecast for $2,247 billion by 2025 (Statista, 2022), a two-fold increase over the previous 15 years (Moorhouse, 2020). When it comes to today's society, fashion has had a significant impact on the social, economic, political, and cultural landscapes (Gu et al., 2020). "Fashion" refers to any style of product or behavior that has gained widespread acceptance among members of a particular social group and is considered to be appropriate for the time and place in which it was introduced (Wazarkar & Keshavamurthy, 2020). It is, as shown in Figure 2.1, a combination of visual looks, comfort, cost, suitability, culture and trend for a people in a particular society.

Consumers today are more aware of the latest fashion trends because of the media's focus on delivering these trends as quickly as possible. As a result, brands have had to develop more responsive design teams, quick manufacturing bases, and stronger marketing strategies to maintain and grow sales (King, 2011). Fashion employs more than 300 million people worldwide (Herrmann, 2017), and as the middle class expands in emerging countries, this has led to overconsumption and a 40 percent reduction in the lifespan of fashion products (Ellen MacArthur Foundation, 2022). The wearer's body context and aesthetic appearance, as well as the social, political, and cultural context in which they live, all play a role in fashion (Townsend & Goulding, 2011).

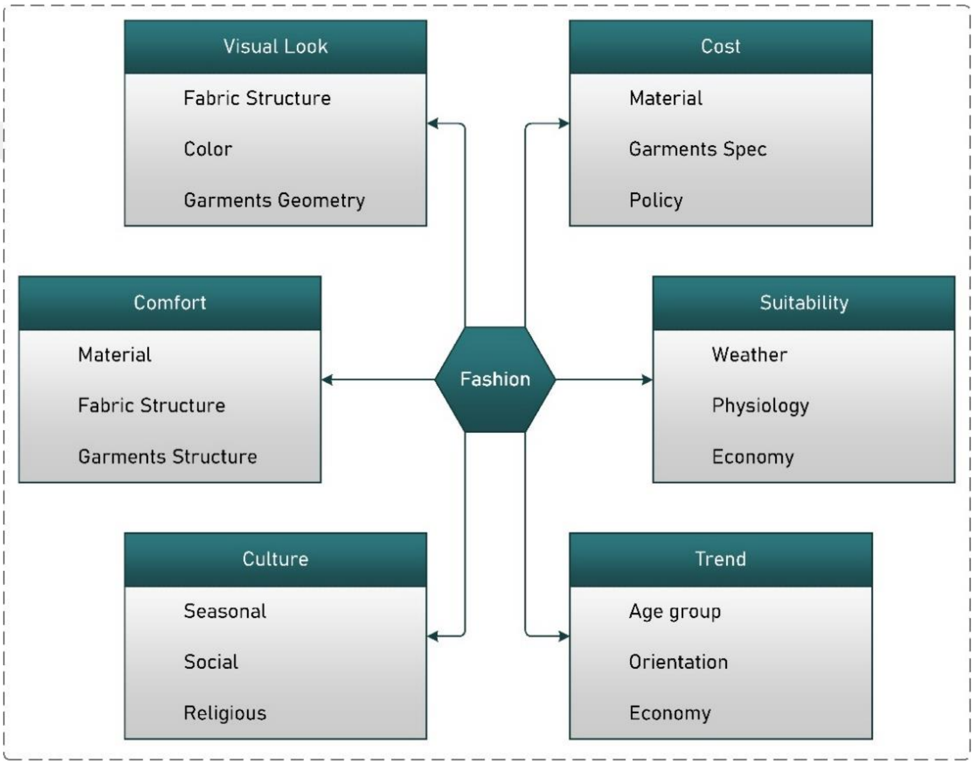


Figure 2.1. Fashion elements

Over sixteen million colors can be distinguished by human eyes. How color is perceived, as well as how it interacts with others and how it is identified, are critical to design and creative endeavors (Dickinson, 2011). High-fashion colors can define a season's look and feel every season. As a result, the availability of these colors may be limited to just a few weeks of the year, or even just one phase of a season (King, 2011). Studies suggest that a specific color is generally less appealing over the years (Chakraborty, 2011). Since consumers have become more fashion-conscious and expect to see new merchandise at every store visit (King, 2011), the fashion industry has adopted a 'fast fashion' approach (Claxton & Kent, 2020) with increased product variation and shorter life cycles to meet consumers' expectations of frequent change in style (Oulton, 2010). As such, the lifespan of an individual fashion trend appears to be moving much more quickly than ever before.

2.4.1. Fashion Elements and Fabric Designer

Fashion designing is a teamwork that comprises selection of fiber type, yarn type, fabric type and fabric geometry, coloration, finishing type, garments geometry and finally, cost connection. The fabric designer as a member of the fashion development team is responsible for developing new ideas and variation in fabric structure and color combination. More and more knitted products are being used in the lifestyle market, which includes fashion, sportswear, clothing, and hosiery (Francis & Sparkes, 2011) and in architecture, composites, medical, and military purposes as technical textiles (Kapllani et al., 2021). The fiber, yarn, knitting, dyeing, printing, or finishing stages can all be used to introduce knitted fabric ornamentation for design purposes (Ray, 2012e). As fiber is the fundamental raw material for textiles, thereby, a variation in the fabric properties can be introduced from fiber stage. There are many types of natural and synthetic fibers which can alone or in blend can be used to impart a different aesthetic, comfort or cost value in the product (Spencer, 2001f). Though fiber properties influence yarn properties to maximum extent, but variation in the constituent fiber proportion, twist direction, TPI, count, texturizing or even production method can induce further property difference in the fabric. Again, uses of several types of yarn in the same fabric is very frequent for technical or fashion purpose.

The most common practice for bringing change in look and feel in knitted fabric is producing fabric with combination of knit, tuck and miss loops in the basic structures (Spencer, 2001o). There are billions of ways to combine these loops on basic structures each of which produces a different derivative with different look and feel (Meißner & Eberhardt, 1998). Design variation can also be implemented by loop transfer (Spencer, 2001m) or by wale fashioning or shaping (Spencer, 2001t). Other modifications include fleece fabric knitting, high pile or sliver knitted fabric production, plush or terry fabric production via laying-in or plating, using yarn changer device or striper, linking, and welt formation (Ray, 2012o).

Color plays an important role in fashion design because it adds an element of surprise and intrigue to the final product (Gaimster, 2015). While some consumers show a tendency to gravitate toward certain color schemes (King, 2012), as a common, color had begun to permeate the lives of consumers and capable of changing customers' purchasing decisions (King, 2017). Therefore, the bulk change in look in fabric is brought by coloration i.e., dying or printing. Digital printing is replacing the traditional printing process for quick response and greater flexibility (Tyler, 2011) with a barrier leaving to the fabric designer that, the surface of the fabric be suitable and smooth enough necessary to satisfy the style requirements of the client base (Briggs-Goode & Russell, 2011). Heat or chemically derived shaping can also be used in the finishing process. As a whole or on a selective basis, the finishing process can completely transform the appearance of an otherwise uninteresting structure (Spencer, 2001f).

2.4.2. Difficulties for Knit Fabric Designer

Creating new designs, structures, and color blends at competitive prices and in a timely manner are essential in today's dynamic fashion market (Ray, 2012a). Despite the fact that companies are increasingly realizing the need for customer-centric strategies to better respond to rapidly changing market demands (Mok et al., 2013), in most cases there are gaps in practice and demand of knitted fabric production in terms of development cycle or fitting quality manner. Faster systems and better response times are now a necessity for businesses competing on the global stage, making the demands placed on manufacturing firms even more onerous. As the number of product variants and small lots grows, it is critical to develop production systems that are quick and highly flexible (Simonis et al., 2016). As a result of the ever-changing nature of the market, a designer's fashion calendar now a days, include up to five collections per year (Moorhouse, 2020) or sometimes even more to come up with changing trends or the seasonal fashion (Jenkyn-Jones, 2011). As a method for fostering creativity and new ideas, design thinking is frequently cited as a promising approach (Kozlowski et al., 2018). Combining intermeshing loops for structural innovation and color combination is infinite (Meißner & Eberhardt, 1998). It is imperative that this creative work be time-consuming, cost-intensive, and trend-sensitive. In order to be a knit designer, the designer needs to be both creative and knowledgeable about a wide range of technological and finishing constraints. They must be knowledgeable about yarn properties, product design, and knitting and manufacturing technology (Francis & Sparkes, 2011). Therefore, they face the difficult task of balancing aesthetic appeal with functional performance for a specific market and end-use (Redmore, 2011) and require effective computational assistance in the core.

As previously mentioned, appreciable developments have been accomplished in textile CAD systems that now enable building complex repeat structures quickly in color and pattern designing (Behera, 2011), and this has facilitated designers to generate far more variations of designs than was previously possible when using traditional methods (Lamar, 2011). Unfortunately, knit fabric designers do not have the same access to advancements as those in the weaving or apparel sectors (Groller et al., 1995). In many cases, design procedures includes a focus on engineering and technical design, as well as the guidance of specialized personnel who express their opinion using only subjective criteria and intuition (Vassiliadis et al., 2007). This lagging perhaps can be attributed to the complexity of intermeshing, lack of universally acceptable knitting geometry or the less attractive market for such system with smaller in nature knit factory showing less financial capability. Stoll and Shima Seiki are two of the most well-known names in knitting

CAD systems, both focus on course gauge weft knitting for sweaters, both the systems are machine dependent, expensive, and within the financial means of large or composite textile companies. Most knitting factories, due to the nature of comparatively small investment and financially less capable project, are unable to bear the cost of a such systems.

2.5. Visual Simulation Models for Knit Fabric

Simulating an object is often done using a model that is an abstraction of the actual object. Be it more important that the model is accurate enough to explain the real issue, rather than that it is precise enough to replicate reality in all aspects (Veit, 2012c). If the thing is to serve its intended purpose, it must have its critical parameters identified and selected in advance (Y. K. Kyosev, 2012). With knit fabric visual simulation system, designers are anticipated to alter the colors and see the effect instantly, as well as see how color and structure fit together (Yordan Kyosev & Renkens, 2010). Mechanical modeling is the use of a set of behavioral principles to approximate and virtually reproduce the mechanical behavior of a fabric. When a fabric's shape and look are intended to be represented, geometrical modeling is then applied with a set of geometrical data (Volino & Magnenat-Thalmann, 2000c). Therefore, loop shape and intermeshing geometry are the base of visual simulation of knit fabric (Poincloux et al., 2018).

For the mechanical or geometric simulation of textiles, a realistic geometric model of fabrics is critical (Lin et al., 2011). Unfortunately, for weft knitted structures, as stated in the preceding section 2.3, there is no universally suitable geometry to fit all types of weft knitted structures. Stitch density is essentially determined by the length of the yarn in each loop, which is independent of the yarn's characteristics and other machine parameters, according to Doyle's geometric model for knitted materials (Ramgulam, 2011). Demiroz model proposed that stitch length and yarn count affect the shape, size, and relative position of the stitches in the structure (Demiroz & Dias, 2000a, 2000b), whereas some researchers believe that, despite being a regular structure, each stitch has some randomness and interconnected loops have elastic properties determined by the yarn (H. Zhong et al., 2001). Because of this sort of disagreement many researchers are working on visual simulation of weft knit fabric either using an already created geometric model in full or partial or with their own model with a specific level of visual resemblance and possibilities. Again some of them are using triangular grid model, polynomial surface model or particle system model (Volino et al., 1995) while some are using spline curve model for the representation of the simulated graphics (Choi & Lo, 2003). Htoo et al. used modified Pierce model and spline curve technique for simulating weft knit fabric (Htoo et al., 2017). Groller, Rau, and Strasser came up with their own parametric skeleton curve for modeling and visualization of knit structure (Groller et al., 1995). Kurbak et al. developed own model for simulating 1x1 rib (Kurbak, 2009), used another model with 3DS-MAX to simulate curling of plain-knit fabric (Kurbak & Ekmen, 2008) and again another model for simulating spirality (Kurbak & Kayacan, 2008). Yinglin Li used his own model and curve anchor technique for visual simulation of knit fabric (Li, 2013), Liu et al. proposed new model for simulating plain structure (Liu et al., 2017) whereas Fong, Li, and Liu used their own model for simulating laid-in weft knitted fabrics (Fong et al., 2021)

Although noticeable development in weft knitting machine, the technology is still not being utilized to its full economic potential (E. J. Power, 2018). This is firstly because the capacity of designers and technicians to program complicated patterns, and second, the time it takes to build prototypes (J. Power, 2007; Taylor & Townsend, 2014). Designers sometimes complain that their designs are not precisely constructed in the machine, whereas technicians believe that the designers do not comprehend machine constraints. Because of the disparity in knowledge between the two professions, it appears that this chasm is widening as technology becomes more sophisticated (Au, 2011). Therefore, a CAD system for fine-gauge circular knitting that can combine structural design flexibility, color combination and machine constraints, and at the same time, affordable to any knit fabric design section may be the best option.

3. MATERIALS AND METHODS

The development process of the suit began with an extensive study of the field, available resources and previous works. As a starting point, detailed algorithms were developed in accordance with the findings of the study. The algorithms and the coding built on top of them were modified, adjusted, and updated over the time in order to keep up better with the field.

To develop the application, the development tools Microsoft Visual Studio 2016 and Dot Net version 4.5 were selected on top of Windows 10 Professional as the operating system. In order to function as a database engine, Microsoft Access Database Engine was used. The development suite has finally been updated to Microsoft Visual Studio 2022, as well as Dot Net version 4.8, in order to ensure future code compatibility with the platform. The work has been tested on every version of Windows from 7 up to and including Windows 11. The system performed flawlessly in all of the environments that were tested.

One of the objectives in this development had been keeping the resource consumption low for the visual simulation module, which had been one of the most difficult tasks. A powerful computer with a significant graphics processing unit for rendering is typically required for visual simulation, which consumes a significant amount of resources in most cases. Coding and simulation algorithms have been repeatedly revised to make the software usable by ordinary computer sets by maintaining its compactness and low resource consumption. This allows the software to work well enough with the built-in Graphics Processing Unit (GPU) while also allowing for faster rendering. When it was all said and done, the final development worked with very low system consumption but provided significantly faster rendering of the fabric view without the use of any additional GPU. The total system has been designed keeping the user interface easy with essential tools very commonly used in the knitting section with a purpose that, any technical person as well as a non-technical designer can understand the interface and can use the tools with minimum effort.

3.1. The Costing Module

The study suggested that, Activity Based Costing system would be the most suitable costing system for knitting section since in produces precise information about costing. Thereby, it was decided that, the software will a comprise a module with ABC system and the costing system was designed with the principle that it takes only required data from suitable person to calculate the product cost.

3.1.1. Architecture of Costing Module

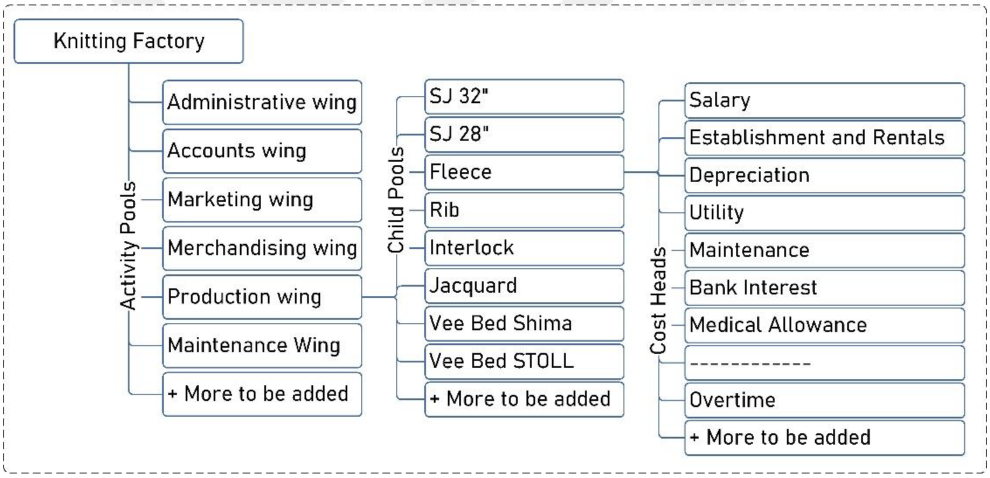


Figure 3.1. Activity Pools and cost heads in a knit factory

For Activity Based Costing system, possible activity pools have been identified. In order to ensure that a knit factory functions as efficiently as possible, several interoperable activity pools collaborate with one another. Activity pools like administration, accounting, marketing, retailing, and maintenance are just a few of the many that are represented in Figure 3.1. These activity pools collaborate to provide assistance to the manufacturing wing. It is possible to break the production wing into sub sections such as a single jersey section, a fleece section, a rib section, an interlock section etc.

Every one of these activity pools, which are composed of both manpower and equipment, can have a variety of cost generating heads, such as salaries, office space rental, equipment rental, depreciation, utility bills, maintenance bills, bank interest, medical allowance, insurance, and overtime bills, to name a few of the expenses. Throughout the course of our investigation, we identified a total of 16 cost heads. The cost heads may vary based on, among other considerations, the nature of the factory and the size of the facility. So, the names of the cost heads have been defined in such a way that they may support any new sub-heads that may be added to the cost heads or new cost heads can be added under a certain activity pool as may be required in the future.

The foundation of the ABC is such that, each activity pool will contain its own cost heads within, and wont share with others unless the second pool require any service from the first said pool. It means, if a section can run without the help of merchandising pool, the section must not bear any cost generated by merchandising. Therefore, the philosophy behind this costing system is the single jersey unit will not bear the expense of maintenance or utility or bank interest from double jersey unit, rather it will only bear the proportional share of administrative, accounting, marketing and such units that really contribute for single jersey section. The same case goes for rib unit or interlock unit or each of sub unit of production unit. Again, more precise control on costing, a big unit can qualify for independent activity pool. For example, a single jersey unit can be further sub divided into many other groups depending upon machine diameter, type of fabric or on the basis of some other parameters. Whenever, a section is qualified as an independent activity pool, the principle applied in this software is, this pool will no longer share or bear any cost from other similar section. It will only bear proportional cost from those sections that directly or indirectly provides service to it. The pool under its own cost heads will encompass all of its own cost and adding up the shared cost for supporting section it will define the its own production cost. Thereby, the costing system is in a way compartmentalization with help tunnels to the relevant supporting units.

A tagging system has been added in the interface to mark a pool whether it is a service pool or a production pool. A service pool is supposed not to produce any physical product rather it offers service or coordination to other pools. On the other hand, a production pool produces physical product or fabric, it takes help or coordination from other service pools. That is why, the cost generated cost by a service pool is distributed to production pool by a proportion of cost driver. The cost heads under each pool have been facilitated with both ‘calculated’ and ‘budgeted’ characteristics. A calculated cost head may have many sub elements. For example, the salary of administrative section is a summation of the salaries of its manpower. The section may have many employees each of which may draw different salary. Therefore, the salary cost head is the summation of the salaries of all its manpower. If the user of the software is authorized to input salary of each employee, the user can expand the cost head and input employee details and salaries. Upon the input, the system, on its own calculate the total salary and show it against salary cost head. If the user is not authorized to know individual salary, rather, for costing purpose, he is only given with the total salary of the section, in that case, the salary is budgeted. The user only inputs the total salary against the cost head. The case can be different for the maintenance cost head because, in the starting of a financial year, the maintenance may be smaller but over the year, the maintenance bill may add up. In this case, a budgeted field is more appropriate because, otherwise, in the initial stage, due to less maintenance cost, the product cost will be less but over the year, the product cost will increase with maintenance cost. Thereby, an estimated maintenance cost for a total financial year may better fit. The estimation may be based on the maintenance bill of previous year or on an average of a month properly evaluated by technical person. On the top interface of the costing module, the authorized person can mark a cost head whether it is calculated or budgeted and the software will behave accordingly by taking the marked bill into consideration.

3.1.2. Cost Driver

Cost driver is the base of any costing system which distributes and attaches the indirect costs to products. If not properly selected, the indirect cost can be wrongly distributed and, particular product type can be overrated while others are underrated. As a consequence, the company may lose its competitiveness in the market with some product type or lose profit from some other product type unknowingly. Again, a single cost driver may sometime become unfit for a factory with multiple product segmentation and different machine type. Therefore, a composite cost driver has been proposed. It is total cost generated by a production pool, a summation of all the cost heads it encompasses like salaries, depreciation, insurance etc. of the respective section. At the same time, a manual cost driver option has been attached where, the authorized person can assign the service costs by an estimated percentage to different production pool. The base of this estimation can be production or salary or any other parameter that the governing body thinks appropriate.

3.1.3. Algorithm for Adding New Activity Pool

While going to add a new activity pool in the software, it will first ask for the name of the pool. If the name exists in the system, it will generate a message informing the duplicity and the process will end. If the user provides a unique name that does not exist in the system, the process as shown in Figure appx-1.1 will proceed, it will generate a unique identification number and attach it with the given name. At the same time, the system will attach default cost heads with the new activity pool, add the pool name in the name pool, and show the newly created pool with all its default cost head on the interface making it the current. Though the interface accepted the new pool, it will not save any data on its own unless the user saves it. Upon saving, the background database will be updated, saved and the new pool name will be available in the cost summary page to be marked as either service pool or production pool. By default, a pool is a production pool and will bear service cost from other pools unless it is marked as service pool. Registration of a new pool ends after saving the newly created pool in the database and gets ready for further modification. If the user makes up mind not to save, though shown in the interface, it will automatically be discarded on next start.

3.1.4. Algorithm for Registering New Raw Material

The primary raw material for a knitting factory is yarn. It can be cotton, polyester, nylon, blend, spandex of different count with different price. Sometimes the raw material is supplied by the buyer himself, in that case, the factory only calculates making cost of the fabric. Thereby, the raw material cost has been kept out of the main calculation algorithm so that if the raw material is supplied by the buyer, the algorithm can correctly calculate the other costing. A separate interface has been added in the software for registering the raw materials.

On initiation of the module, as shown in Figure appx-1.2, the software takes the name or identification keyword of the raw material and checks if the same name exists in the database. If the name exists, it generates an error message informing the duplicity. On getting the unique name, it generates an internal identification and collects some related information about the raw material temporarily. Though the information is displayed on the interface, it is temporary meaning that if not save, the database will not be updated. Upon saving the information by the user, the system updates the main database and makes the information available in the product costing interface.

A fabric can be made of mixed yarn, i.e., two types of yarn. The most common use of this type is adding spandex with base yarn for better elastic property specially in ladieswear. In that case, the software automatically calculates combine yarn price depending on the usage and wastage percentage.

3.1.5. Algorithm for Production Cost Calculation

On initiation of the module, it first identifies how many activity pools are there in the pool and takes one sequentially. Against each activity pool, it takes a cost head into account, checks its nature whether it is calculated or budgeted. If calculated, it goes to take summation of each sub cost heads and adds up to the pool.

If the cost head is marked as budgeted, it directly takes the amount and adds up to the pool and goes for the next cost head. This way, if calculation of all the cost heads is completed, it then goes for the next activity pool. When all the activity pools are calculated, it then starts grouping all the pools as service pools and production pools and calculates the summation of both types individually as shown in Figure appx-1.3. The next step is to define the cost driver. If the cost driver is custom, it divides the service pool cost in that proposition and adds up with the respective production pool. If the cost driver is set to automatic by the user, it then splits the cost of the service pool against individual weight value of each member in the production pool and adds up the portion with the respective pool. This way, the total cost of the factory is assigned to production pools that really produce a consumer product.

3.2. Calculation Module

3.2.1. Count Conversion Table

When expressing the fineness of yarn, there are two fundamental ways to do so: (a) direct system by specifying how much a specific length of yarn weighs; and (b) indirect system by specifying how much the lengths of yarn there are in a certain weight. This way of stating the fineness of yarn is called yarn numbering in the general literature and commonly termed as count (Lord, 2003).

Table 3.1. Count conversion table (Iyer et al., 2004)

Count System	Short Form	den	$ktex$	tex	$dtex$	$mtex$	Nm	Ne	Ne_L	Ne_K	Ne_W
Denier	den	-	$0.00011 \times den$	$0.111 \times den$	$1.111 \times den$	$111 \times den$	$\frac{9000}{den}$	$\frac{5315}{den}$	$\frac{14882}{den}$	$\frac{7972}{den}$	$\frac{17440}{den}$
Kilo Tex	$ktex$	$9000 \times ktex$	-	$1000 \times ktex$	$10000 \times ktex$	$1000000 \times ktex$	$\frac{1}{ktex}$	$\frac{0.590}{ktex}$	$\frac{1.654}{ktex}$	$\frac{0.886}{ktex}$	$\frac{1.938}{ktex}$
Tex	tex	$9 \times tex$	$0.001 \times tex$	-	$10 \times tex$	$1000 \times tex$	$\frac{1000}{tex}$	$\frac{590}{tex}$	$\frac{1654}{tex}$	$\frac{886}{tex}$	$\frac{1938}{tex}$
Deci Tex	$dtex$	$0.90 \times dtex$	$0.0001 \times dtex$	$0.10 \times dtex$	-	$100 \times dtex$	$\frac{10000}{dtex}$	$\frac{5900}{dtex}$	$\frac{16540}{dtex}$	$\frac{8860}{dtex}$	$\frac{19380}{dtex}$
Mili Tex	$mtex$	$0.009 \times mtex$	$0.000001 \times mtex$	$0.001 \times mtex$	$0.01 \times mtex$	-	$\frac{1000000}{mtex}$	$\frac{590000}{mtex}$	$\frac{1654000}{mtex}$	$\frac{886000}{mtex}$	$\frac{1938000}{mtex}$
Metric	Nm	$\frac{9000}{Nm}$	$\frac{1}{Nm}$	$\frac{1000}{Nm}$	$\frac{10000}{Nm}$	$\frac{1000000}{Nm}$	-	$0.590 \times Nm$	$1.654 \times Nm$	$0.886 \times Nm$	$1.938 \times Nm$
English Count	Ne	$\frac{5315}{Ne}$	$\frac{0.590}{Ne}$	$\frac{590.5}{Ne}$	$\frac{5900}{Ne}$	$\frac{590000}{Ne}$	$1.693 \times Ne$	-	$2.80 \times Ne$	$1.50 \times Ne$	$3.280 \times Ne$
Linen	Ne_L	$\frac{14882}{Ne_L}$	$\frac{1.654}{Ne_L}$	$\frac{1654}{Ne_L}$	$\frac{16540}{Ne_L}$	$\frac{1654000}{Ne_L}$	$0.605 \times Ne_L$	$0.357 \times Ne_L$	-	$0.536 \times Ne_L$	$1.172 \times Ne_L$
Worsted	Ne_K	$\frac{7972}{Ne_K}$	$\frac{0.886}{Ne_K}$	$\frac{886}{Ne_K}$	$\frac{8860}{Ne_K}$	$\frac{886000}{Ne_K}$	$1.129 \times Ne_K$	$0.667 \times Ne_K$	$1.867 \times Ne_K$	-	$2.188 \times Ne_K$
Woolen	Ne_W	$\frac{17440}{Ne_W}$	$\frac{1.938}{Ne_W}$	$\frac{1938}{Ne_W}$	$\frac{19380}{Ne_W}$	$\frac{1938000}{Ne_W}$	$0.516 \times Ne_W$	$0.305 \times Ne_W$	$0.853 \times Ne_W$	$0.457 \times Ne_W$	-

Based on these two fundamentals, several counting systems has been adopted for different types of yarn. They are Denier and Tex, mostly used as direct count system and, Metric, English Count, Linen, Worsted and Woolen for indirect count system. Each of the count system is defined by a specific measurement system and dominantly used for particular fiber type in yarn in the factory. For example, English Count (N_e) is mostly used for cotton yarn whereas Tex is for synthetic and Denier for spandex.

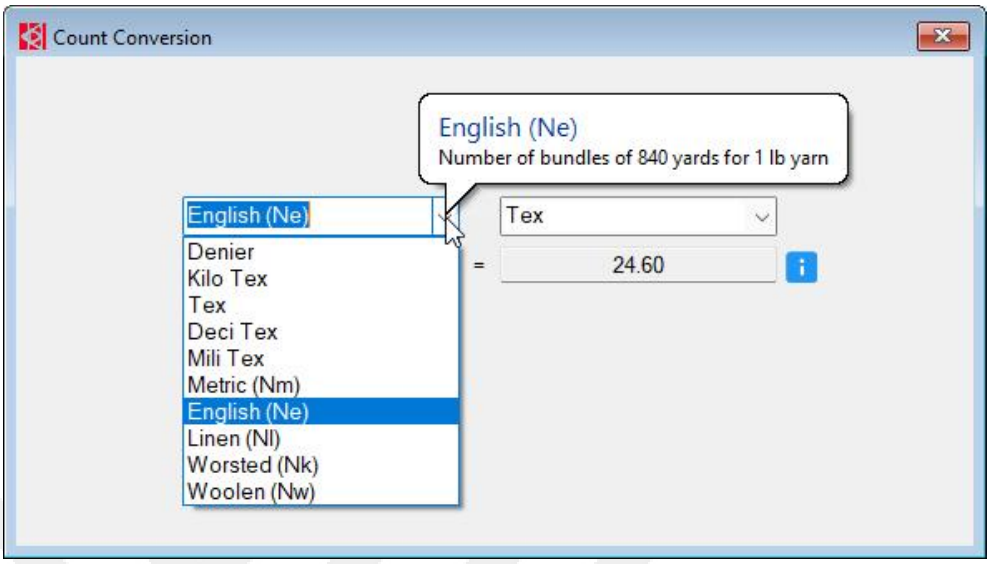


Figure 3.2. Count conversion interface

The term 'Denier' refers to the weight in grams of 9000m yarn. The term 'Kilo Tex' means the weight in kilograms of 1000m yarn, whereas 'Tex' refers to the weight in grams of similar length yarn. 'Deci Tex' refers to the weight in grams of 1000m yarn, whereas 'Milli Tex' refers to the weight in milligrams of similar length of yarn. In the metric count system, Nm denotes the length in kilometers of a kilogram of yarn; in the English count system, Ne denotes the number of bundles of yarn in a pound, with each bundle containing 840 yards of yarn. Linen count system 'Li' is defined as the number of 300-yard bundles in one-pound, Worsted count system 'Nk' is defined as the number of 560-yard bundles in one pound, and Woolen count system 'Nw' is defined as the number of 256-yard bundles in one pound yarn.

The technical person responsible in the production line generally uses a conversion table as shown in Table 3.1, to calculate the yarn count for characterization of the fabric when two or more types of yarn are used. In the calculation module of the software, this conversion table as shown in Figure 3.2, has been coded so that the user can easily convert a count system to another. For an explanation to the non-technical person, a short definition of the count system selected has been added also which pops up briefly when the mouse hovers.

3.2.2. Fabric Characterization

As discussed in the previous section, there is no universally established mathematical model or formulation that can explain the properties of knit fabrics without uncertainty. But as a dominant business sector, knit fabrics also requires characterization, also requires property prediction before going to actual production for selection of raw materials and setting of machine parameters. Thereby, for the sake of minimizing trials and keep the business on track, a set of equations are used relating yarn parameters, fabric parameters and machine parameters (Pavko Čuden, 2010).

These equation sets are sometimes deduced by technical persons in the industry, some of them can be related to geometrical models but none of the full sets does go to any single source and none of the equations is applicable without tolerance, therefore, they are used as estimation. Since these equations are not always universally established, they can be used in various forms in various locations of the world.

The most common parameters used in case of knit fabric in the factory are production by length, production by weight, fabric width, GSM and related parameters and elastane content. Each of these parameters correlate other parameters either from yarn or from machine. For example, the GSM, as shown in Figure 3.3, includes machine gauge, stitch length and yarn count which are very important for selection of machine, machine settings and raw material for a fabric with particular characteristics. Some of the important equations with their varying forms are as follows.

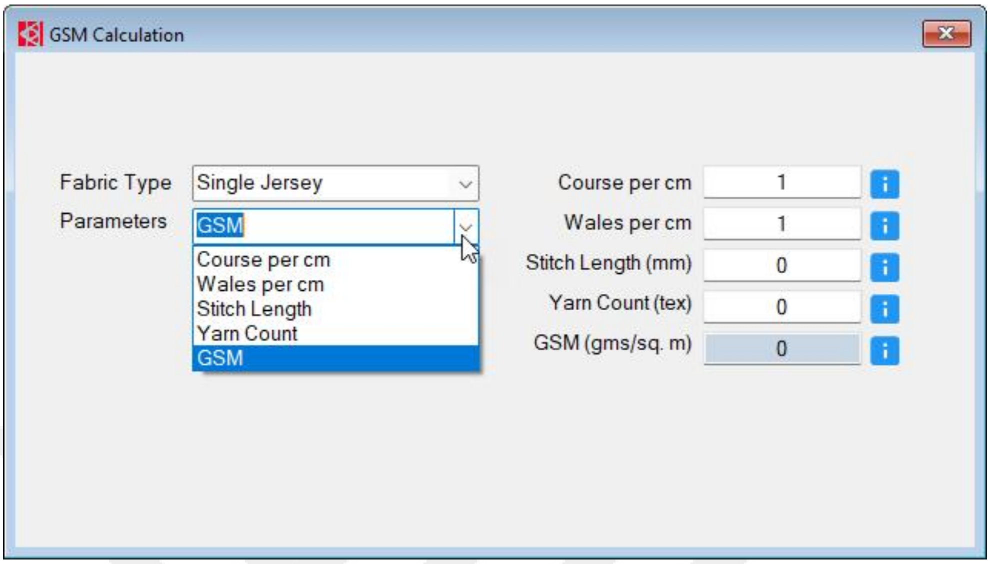


Figure 3.3. GSM and related parameter calculation interface

$\boldsymbol{a. Production\ by\ length_{meter\ /\ hour}}$

$$= \frac{Course\ per\ hour}{Course\ per\ meter \times Feeder\ per\ Course}$$

$$= \frac{Machine\ RPM\ \times 60 \times No.of\ Feeders \times Eff\%}{Course\ per\ inch \times 39.37 \times\ Feeder\ per\ Course}$$

$$= \frac{Machine\ RPM \times\ No.of\ Feeders \times Eff\%}{Course\ per\ inch \times\ Feeder\ per\ Course} \times 1.524 \qquad \text{..... (3.1)}$$

$$= \frac{Machine\ RPM \times\ No.of\ Feeders \times Eff\%}{Course\ per\ cm\ \times 2.54 \times\ Feeder\ per\ Course} \times 1.524$$

$$= \frac{Machine\ RPM \times\ No.of\ Feeders \times Eff\%}{Course\ per\ cm\ \times\ Feeder\ per\ Course} \times 0.60 \qquad \text{..... (3.2)}$$

[Feeder per Course=1 for Single Jersey and Rib, for Interlock it is 2;

RPM = Revolution of cylinder per minute.]

$$\boldsymbol{b. Fabric\ witdth_{meter}}$$

$$= \frac{\pi \times\ Machine\ Diameter_{inch} \times Gauge}{Wales\ per\ cm\ \times 100} \quad \text{.............................. (3.3)}$$

[Gauge = Number of needles in one inch in the machine.]

$$\boldsymbol{c. Production\ by\ weight_{kg\ /\ hour}}$$

$$= \frac{Production\ per\ hour\ in\ length_{meter}\ \times\ Farbic\ Width_{meter}\ \times GSM}{1000} \quad \text{..... (3.4)}$$

$$= RPM\ \times no. of\ Feeders \times Eff\% \times Dia_{inch} \times \frac{Gauge \times Needle\ Bed \times Sl_{mm} \times 0.0001113}{Count_{Ne}} \quad \text{.. (3.5)}$$

$$= RPM\ \times 60 \times no. of\ Feeders \times Eff\% \times \pi \times Dia_{inch} \times \frac{Gauge \times Needle\ Bed \times Sl_{mm} \times Count_{Tex}}{1000 \times 1000 \times 1000} \quad \text{.. (3.6)}$$

$$= RPM\ \times 60 \times no. of\ Feeders \times Eff\% \times \pi \times Dia_{inch} \times \frac{Gauge \times Needle\ Bed \times Sl_{mm} \times Count_{den}}{1000 \times 1000 \times 1000 \times 9} \quad \text{.. (3.7)}$$

[GSM = Grams per square meter of the fabric, (g/m^2)]

$$\boldsymbol{d. GSM\ of\ the\ fabric}$$

$$= \frac{Course\ per\ inch\ (CPI) \times Wales\ per\ inch\ (WPI) \times\ Sl_{mm}}{Yarn\ Count_{Ne}} \times 0.915 \quad \text{.... (3.8)}$$

$$= CPI \times WPI \times\ Yarn\ Count_{Tex} \times\ Sl_{mm} \times 0.00155 \quad \text{................ (3.9)}$$

$$= \frac{K_s \times \ Yarn\ Count_{Tex}}{Sl_{mm}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.... (3.10)$$

[K

[K_s= Loop Constant]

$e.\ \boldsymbol{Lycra\%\ in\ the\ fabric}$

$$= \frac{l_{lycra}\ \times Lycra\ Count_{tex} \times 100 \times Feeder\ Ratio}{l_{yarn}\ \times Yarn\ Count_{tex} + l_{lycra}\ \times Lycra\ Count_{tex}} \qquad \ldots\ldots\ldots\ldots.... (3.11)$$

[l = length of yarn or lycra in similar unit]

3.3. Fabric Design and Development Module

For the simulation of knit fabric, it was necessary to define four parameters for an intermeshed loop or stitch. They are height and width of the loop, and jamming condition in the height and width direction. These parameters need to corelate yarn count, stitch length and machine gauge as primary variables. Since, knit fabric can't be produced without knit loop, therefore, the four parameters were defined against knit loop which automatically fits for tuck, held or miss loops also.

3.3.1. Intermeshed Loop Geometry

For defining parameters, a simplified geometric model for intermeshed loop as shown in Figure 3.4 is proposed. In the model, a set of assumptions was made by analyzing several single jersey knit fabric both plain and derivative types. The assumptions for the knit loop are:

a. The loop is symmetric along line EF.
b. In the left half, the upper interlocking point is at the intersection point of IJ and KL.

c. In the left half, the lower interlocking point is at the intersection point of KL and MN.
d. With the increase of yarn diameter, the center point of yarn diameter ‘C’ moves to left direction until the yarn touches OA and creates jamming.
e. ‘B’ is also the center point of yarn diameter, which with the increase of yarn diameter moves to right direction until the yarn touches EF and creates jamming.
f. With the increase of yarn diameter, ‘D’ moves downward until it touches IJ.
g. The maximum width of a loop is defined by machine gauge.
h.

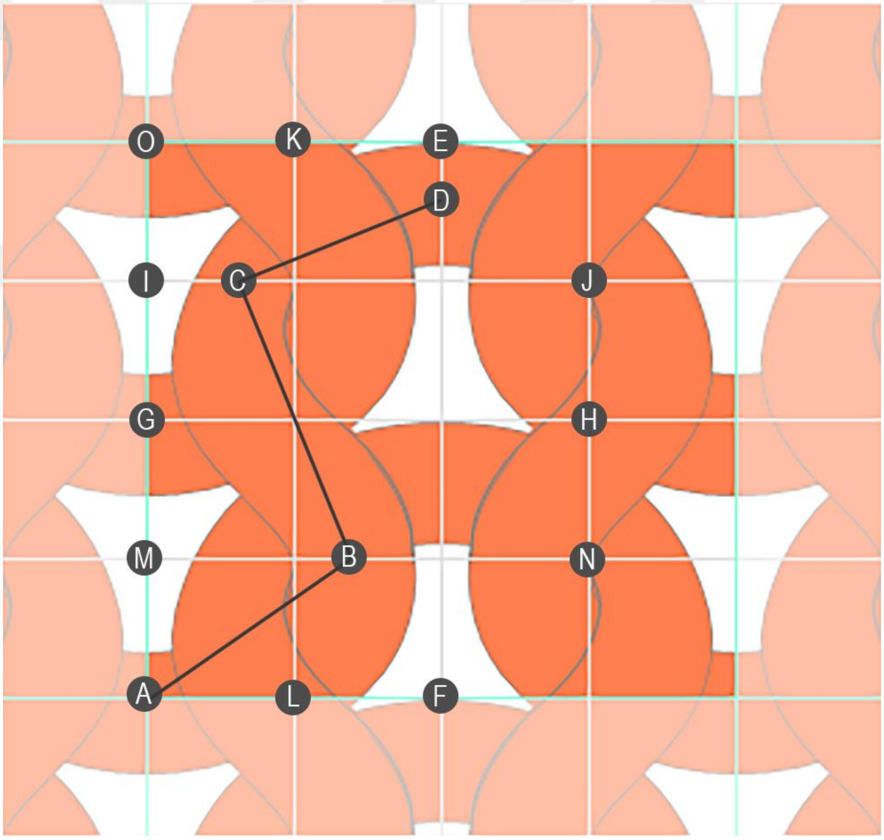


Figure 3.4. A knit loop in intermeshed state

Height of the loop: According to Figure 3.4, ignoring curvature of the yarn and assuming that the yarn is straight from A to B, B to C and C to D, we get-

$$Length\ of\ the\ Yarn = 2 \times (AB + BC + CD) \qquad \text{……………………….. (3.12)}$$

$$AB^2 = \left(\frac{P}{4} + \frac{Y_d}{2}\right)^2 + (Y_d)^2$$

$$BC^2 = (H - 2Y_d)^2 + (Y_d)^2$$

$$CD^2 = \left(\frac{P}{4} + \frac{Y_d}{2}\right)^2 + \left(\frac{Y_d}{2}\right)^2$$

$$\therefore\ Sl_{mm} = 2 \times \left(\sqrt{\left(\frac{P}{4} + \frac{Y_d}{2}\right)^2 + (Y_d)^2} + \sqrt{(H - 2Y_d)^2 + (Y_d)^2} + \sqrt{\left(\frac{P}{4} + \frac{Y_d}{2}\right)^2 + \left(\frac{Y_d}{2}\right)^2}\right) \qquad \text{…. (3.13)}$$

$$Yarn\ Diameter\ Yd_{mm} = \frac{25.4}{28 \times \sqrt{N_e}} = \frac{0.907}{\sqrt{N_e}}\ and \qquad \text{…………….. (3.14)}$$

$$Pitch\ of\ the\ Cylinder\ P = \frac{25.4}{G}\ mm \qquad \text{…………….. (3.15)}$$

$$\therefore\ Sl_{mm} = 2 \times \left(\sqrt{\left(\frac{25.4}{4G} + \frac{0.907}{2\sqrt{N_e}}\right)^2 + \left(\frac{0.907}{\sqrt{N_e}}\right)^2} + \sqrt{\left(H - \frac{2 \times 0.907}{\sqrt{N_e}}\right)^2 + \left(\frac{0.907}{\sqrt{N_e}}\right)^2} + \sqrt{\left(\frac{25.4}{4G} + \frac{0.907}{2\sqrt{N_e}}\right)^2 + \left(\frac{0.907}{2\sqrt{N_e}}\right)^2} \right) \quad \ldots\ldots\ldots\ldots\ldots (3.16)$$

$$for\ simplicity, let\ a = \left(\frac{25.4}{4G} + \frac{0.907}{2\sqrt{N_e}}\right), b = \frac{0.907}{2\sqrt{N_e}}\ and\ Sl_{mm} = c$$

$$\therefore\ Sl_{mm} = 2 \times \left(\sqrt{a^2 + 4b^2} + \sqrt{(H - 4b)^2 + 4b^2} + \sqrt{a^2 + b^2}\right)$$

$$or, 2\left(\sqrt{a^2 + 4b^2} + \sqrt{(H - 4b)^2 + 4b^2} + \sqrt{a^2 + b^2}\right) - Sl_{mm} = 0$$

$$or, \sqrt{a^2 + 4b^2} + \sqrt{(H - 4b)^2 + 4b^2} + \sqrt{a^2 + b^2} - \frac{Sl_{mm}}{2} = 0$$

$$or, \sqrt{(H - 4b)^2 + 4b^2} = \frac{Sl_{mm}}{2} - \sqrt{a^2 + 4b^2} - \sqrt{a^2 + b^2}$$

$$or, (H - 4b)^2 + 4b^2 = \left(\frac{Sl_{mm}}{2} - \sqrt{a^2 + 4b^2} - \sqrt{a^2 + b^2}\right)^2$$

$$or, (H - 4b)^2 = \left(\frac{Sl_{mm}}{2} - \sqrt{a^2 + 4b^2} - \sqrt{a^2 + b^2}\right)^2 - 4b^2$$

$$or, H - 4b = \pm\sqrt{\left(\frac{Sl_{mm}}{2} - \sqrt{a^2 + 4b^2} - \sqrt{a^2 + b^2}\right)^2 - 4b^2}$$

$$\therefore\ H = 4b \pm \sqrt{\left(\frac{Sl_{mm}}{2} - \sqrt{a^2 + 4b^2} - \sqrt{a^2 + b^2}\right)^2 - 4b^2}$$

Accepting the meaningful value for H, we get

$Height\ of\ the\ loop, H_{mm}$

$$= 4b + \sqrt{\left(\frac{Sl_{mm}}{2} - \sqrt{a^2 + 4b^2} - \sqrt{a^2 + b^2}\right)^2 - 4b^2}$$

Now, substituting a and b, we get

$$= 4 \times \left(\frac{0.907}{2\sqrt{N_e}}\right) + \sqrt{\left[\left\{\frac{Sl_{mm}}{2} - \sqrt{\left(\frac{25.4}{4G} + \frac{0.907}{2\sqrt{N_e}}\right)^2 + 4 \times \left(\frac{0.907}{2\sqrt{N_e}}\right)^2} - \sqrt{\left(\frac{25.4}{4G} + \frac{0.907}{2\sqrt{N_e}}\right)^2 + \left(\frac{0.907}{2\sqrt{N_e}}\right)^2}\right\}^2 - 4 \times \left(\frac{0.907}{2\sqrt{N_e}}\right)^2\right]}$$

$$= \frac{1.814}{\sqrt{N_e}} + \sqrt{\left[\left\{\frac{Sl_{mm}}{2} - \sqrt{\left(\frac{6.35}{G} + \frac{0.454}{\sqrt{N_e}}\right)^2 + \frac{0.823}{N_e}} - \sqrt{\left(\frac{6.35}{G} + \frac{0.454}{\sqrt{N_e}}\right)^2 + \frac{0.206}{N_e}}\right\}^2 - \frac{0.823}{N_e}\right]} \quad \text{……………(3.17)}$$

[where H = Loop height (mm), P = Cylinder pitch (mm), Y_d = Yarn diameter (mm), Sl = Stitch length (mm), G = Number of needles in one inch, N_e = English cotton count]

This equation constitutes relation among machine gauge, yarn diameter, stitch length and loop height.

Width of the loop: According to the assumption made, the maximum width of the loop is equal to the pitch in the cylinder.

Jamming condition in loop width direction: A relation was necessary between the count of the yarn and machine gauge to identify the yarn jamming in loop width direction.

$$Yarn\ Diameter\ d_{inch} = \frac{1}{28 \times \sqrt{N_e}}\ or\ d_{mm} = \frac{25.4}{28 \times \sqrt{N_e}} \quad \text{………. (3.18)}$$

$$For\ avoiding\ width\ Jamming, Needle\ Pitch\ must\ be\ greater\ than\ 4 \times d$$

$$or, P_{mm} \geq 4 \times d_{mm}$$

$$or, \frac{1 \times 25.4}{Machine\ Gauge} \geq \frac{4 \times 25.4}{28 \times \sqrt{N_e}}$$

$$or, \frac{1}{G} \geq \frac{1}{7 \times \sqrt{N_e}}\ or, 7 \times \sqrt{N_e} \geq G$$

$$\therefore\ N_e \geq \frac{G^2}{49} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.19)$$

Jamming condition in loop height direction: As illustrated in Figure 3.4, the height of the loop cannot be less than three times of yarn diameter. Thereby –

$$Height\ of\ the\ loop\ in\ mm, H_{mm} \geq 3 \times yarn\ diameter$$

$$or, H_{mm} \geq 3 \times \frac{25.4}{28 \times \sqrt{N_e}}$$

$$\therefore\ H_{mm} \geq \frac{2.721}{\sqrt{N_e}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.20)$$

Height of a Tuck Loop:

$$H_T = H_k + \frac{n \times H_k}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.21)$$

[H_T = Height of Tuck loop in mm, H_k = Height of knit loop in mm, n = Number of skipped courses]

Height of a Held Loop:

$$H_H = H_k + \frac{n \times H_k}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.22)$$

[H_H = Height of Held loop in mm, H_k = Height of knit loop in mm, n = Number of skipped courses]

Using the above equations and interlocking points as mentioned in the assumptions of the geometric model, the algorithm was developed to characterize a single loop of any type which in combination with other loops, generate the visual of the simulated fabric.

3.3.2. The Single Jersey Module

The single jersey module is capable of handling both plain single jersey and single jersey derivatives of all kinds. It follows a six-step process that includes notation diagram creation, validation, machine setup, coloration, and fabric simulation. Figure 3.5 shows the module's interface, which includes a graph paper with single jersey gating system, a toolbar with necessary tools, a library combo for accessing saved designs, and a panel on the right side with fabric information and machine setup parameters. A column of cells on the graph paper's left side offers color selection for each course when clicked, bringing up a color palette with all of the windows' built-in colors. The toolbar above includes color selection and filling tools, as well as functions for creating, deleting, and saving. Because a single jersey plain or derivative is made up entirely of face knit, tuck, or miss loops, thereby back loops are not available in this module. The graph paper context menu includes options for validating the structure, determining machine setup, and opening the simulation window. The simulation window displays the default fabric view of the given structure at first, but when updated, it displays the actual fabric view. Parameters that affect the fabric view have been attached to the right panel of the simulation window so that the user can change the parameters and update the view accordingly.

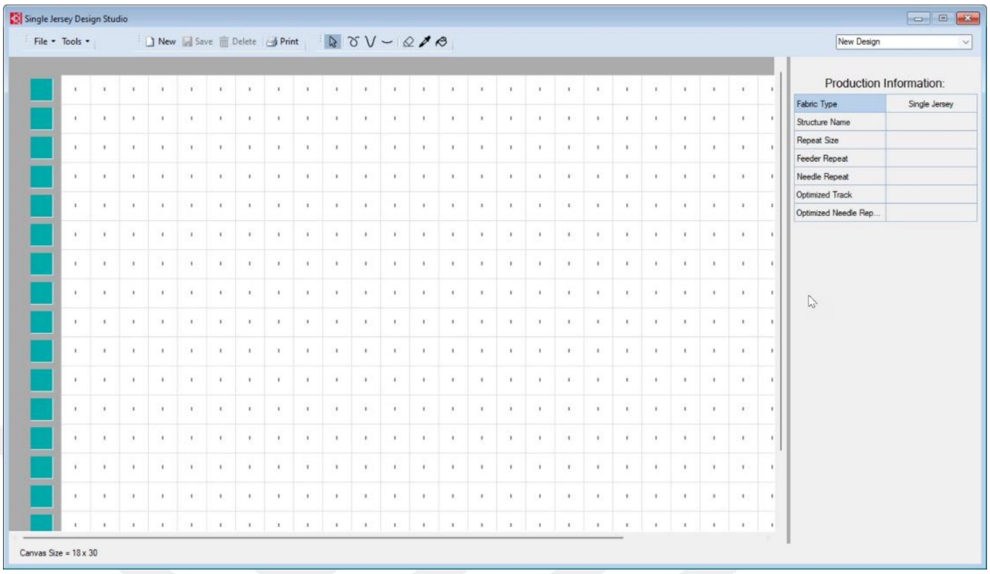


Figure 3.5. Interface of single jersey module

3.3.2.1. The Single Jersey Parent Algorithm

To work smoothly, the single jersey parent module is interconnected with several supporting modules, as shown in Figure 3.6. When the main module is started, it also loads the design and library modules. With cut, copy, and paste capabilities, the design module can handle all types of design development and coloration work. The storage module is in charge of digitizing the notation diagram and color information and saving it to a database. The library module is in charge of retrieving saved designs and color information from the database. The modification module is useful in situations where a user does not finish a design but leaves it half-finished and wants to finish it later. This module is capable of handling any type of structural or color change.

As discussed earlier, the freedom of designers is limited by the capacity of the machine that will be used to make the actual fabric. As a result, the designer must determine whether the developed structure will exceed the machine’s capacity. Again, a large structure could have an unwelcome flaw, such as missing stitches in courses. All of these flaws are addressed by the validation module. It examines the structure’s integrity and alerts the user if there is a problem. This module is loaded automatically prior to determining machine setup or simulation, or it can be started manually from the context menu.

The machine setup module is primarily intended to assist the technician in producing the designed fabric in the machine. This module takes over after the validation and calculates two types of cam setup and needle setup for the production. If you start with a linear setup with no needle or cam optimization. It recalculates the cams and needles for further optimization and displays the results on the right panel in response to a command.

Fabric combining the loops placed in the notation with color is used in the simulation module to convert notation diagrams into actual fabric visuals. It gives the user the option to change the yarn count, machine gauge, and stitch length, which are the most important parameters for knit fabrics, after default loading. After loading the module, the user can either begin working with the design module or load a design from the library before proceeding to validation. After simulation, he can go back and make changes, such as changing the stitch or colors, and saving the design in the database or as an image for use as an example.

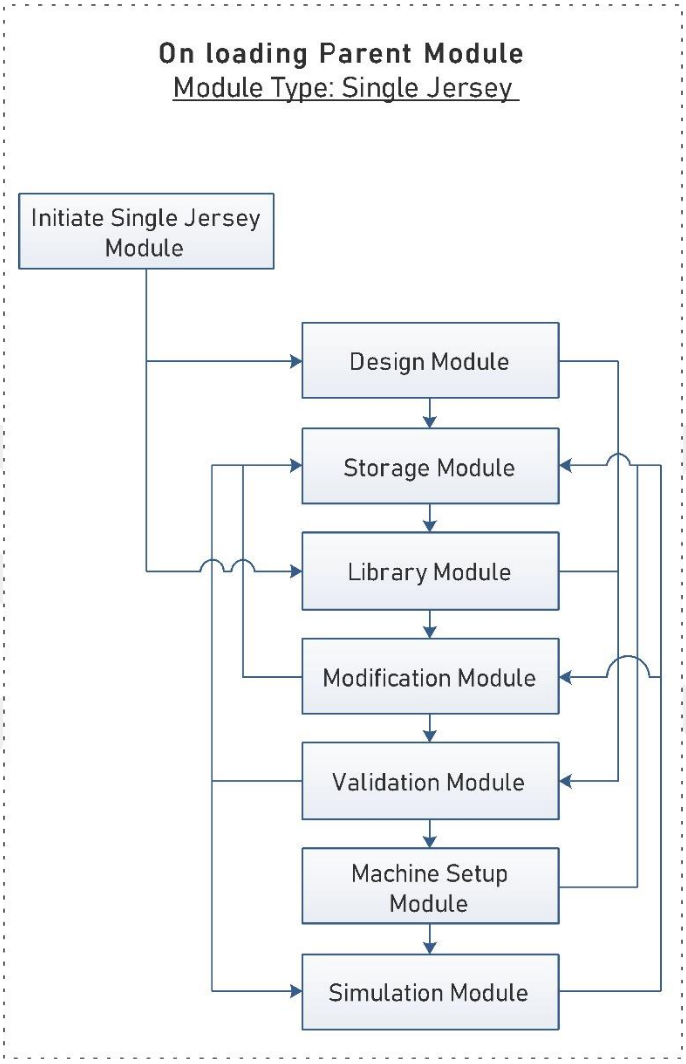


Figure 3.6. Composition of the single jersey module

3.3.2.2. The Design Module

The design module, upon initiation loads with default canvas setting with predefined number of course and wales spaces. If the user ignores the default canvas and initiates another new one, a popup window takes the number of courses and wales required.

If any error occurs in the input the system generates an error message. Otherwise, it displays a graph paper according to the input given. After preparing the graph paper, the module calls needle gating module to prepare the gating according to single jersey machine and display it over the graph paper. It then goes for preparing the color palette. The color cells one for each column is displayed on the left of each course loaded with a default color and ready to be changed according to users' wish. The algorithm for the design module in single jersey is shown in Figure appx-1.4.

In the background, the system needs to prepare data regarding every loop user places on the canvas. Thereby, it first assigns a predefined loop value to each cell on the graph paper and stores it temporarily. Similar way, it also needs to keep track of each color that the user defines for courses in the structure. It first prepares a color value array for each course in the canvas and stores it temporarily. The necessary tools for developing the notation diagram or modification along with tools associated with file handling are loaded with the parent module. If the user wishes to save the work, this module will call the storage module for necessary validation and database handling. Otherwise, the temporarily done job is discarded if the user moves to another design studio like rib or interlock.

3.3.2.3. The Canvas Module

This module is automatically called from the design module upon its loading or the user can call it while opening new design in the single jersey module. If it is called by design module, it provides some default values for initiating the design module but if it is called by user upon creating new design, it receives input from user, invalidates the existing canvas and initiates a new canvass loading so that the user can design new structure from scratch.

As shown in Figure appx-1.5, the module takes number of course, number of wales and cell size of the graph paper from the user. It then calculates the size of the graph paper requested and calls the graph module to generate it accordingly on the canvas. At the same time, it initiates notation bitmap that will convert the notation drawn by the user to a from to generate notation graphics to be displayed on the screen and suitable for further processing.

3.3.2.4. The Graph Module

This module takes information from the previous module and calculates the width and height necessary for the canvas. It then takes default parameters for drawing pen and draws vertical lines with cell space defined by the user. When canvass width is reached, it then starts drawing horizontal lines with same cell space until it reaches height of the canvas. On completion of drawing graph, it then updates the notation graphics and updates the screen to show the graph paper. In the graph paper, each row represents a course, and each column represents a wale of the knit fabric to be designed. The algorithm of the graph paper is shown in Figure appx-1.6.

3.3.2.5. The Needle Bed Module

This module loads after the completion of the graph module. A single jersey machine, unlike rib or interlock, operates with one set of needles. therefore, the needle arrangement is linear. Upon initiation of the module, it determines number of cells generated by the graph paper on the canvass and considers each cell a holding place of a loop. It then, as shown in Figure appx-1.7, sequentially puts needle mark on each cell, prepares default needle code and calls color palette module.

3.3.2.6. The Color Palette Module

This module is responsible for offering color combination facility against each course in the structure. Upon loading, it first identifies the number of courses defined and the cell size from which it calculates height and width of the color palette required. It then defines the location of the color palette so that each cell corelates with a course in the structure and the user with minimum difficulty can access and use it. It starts with first course and draws clickable color box on the left side of the course. Then checks if the last course is reached, if not, takes the second course and draws color box with default color for the second course and this way goes on until it reaches last course. After drawing all the color box, it then updates color graphics and updates the screen. The algorithm is shown in Figure appx-1.8.

It then starts second loop where it takes all the values of colors it has put on the boxes against each course and converts those codes to a specially formatted color code easily interpretable in red, green and blue component by the software and stores them temporarily. Each of the color box is responsive and upon user interaction, it calls windows default color dialogue with full range of colors windows can offer. User can select any color from the color dialogue or can define new color by changing red, green, blue (RGB) values or hue, saturation and chroma. The defined new color is at once reflected in the active color cell if the user accepts or retains the old color if the user changes his mind and wants to keep the previous one.

Change of any color in the color cell at once changes the color of the corresponding row in the canvas and thereby the color of the loop notation in that row. Since a row or a course in single jersey knit fabric is made with only one yarn, a row in the canvas can’t accept multiple color or color mix at the same time. In other words, unless jacquard, a column or a wale in the single jersey fabric can’t separately accept different color. That is why, the color changing option is only available along the row or along the course of the structure.

3.3.2.7. The Notation Module

There are some commonly adopted symbolic loop notation for knit structure as shown in Table 3.2 which technical persons use while representing a knitted structure. When these notations are meaningfully combined to represent a knit fabric, the combination is called notation diagram. The similar notations have been adopted in the software so that it remains familiar to the users. Figure 3.7 shows notation diagram with face loops for a single jersey derivative fabric.

Table 3.2. Notation used in the software

Cylinder Loops		Dial Loops	
Notation	Meaning	Notation	Meaning
	Cylinder Knit Loop or Face Knit Loop		Dial Knit Loop or Back Knit Loop
	Cylinder Tuck Loop or Face Tuck Loop		Dial Tuck Loop or Back Tuck Loop
	Cylinder Miss Loop or Face Miss Loop		Dial Miss Loop or Back Miss Loop

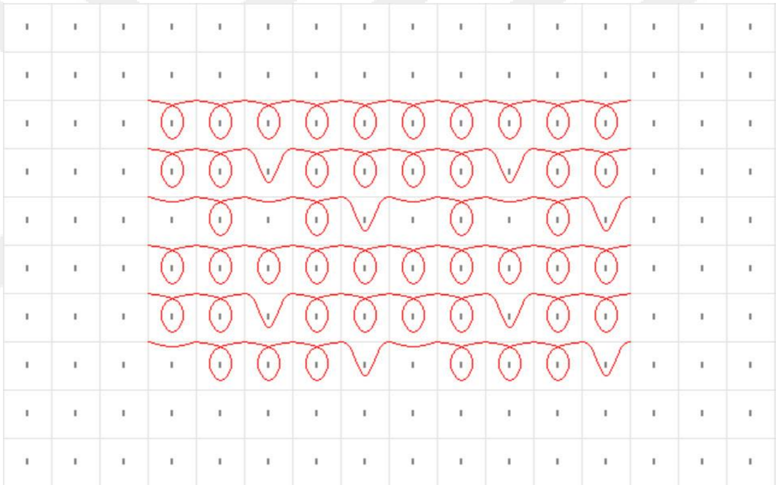


Figure 3.7. Notation diagram of a single jersey derivative

The notation module, on loading, calculates total number of cells on the canvass and assigns a default notation value for each empty cells. Assigning cell value for each cell sequentially takes a longer time, therefore, as shown in Figure appx-1.9, it at first takes number of cells in a course and assigns values. Since the canvas is yet to be modified, it assigns empty value and then copies the same value for all the other courses by appending with first course and stores the total value in a temporary memory.

3.3.2.8. The Storage Module

The storage module handles all the tasks related to database updating regarding saving a new design, renaming an existing design or completely delete a design from the database. It is initiated if the user clicks on save icon or initiates save command. On initiation, the module fist identifies if the structure is previously saved and modified, or it is a new structure. If the structure is not new, but modified, the module first identifies the changes in courses and wales, colors and structural modification from the temporary memory. It then sends the changes to the database. If there occurs any error while updating database it generates error message, otherwise it waits for the next command. The algorithm has been illustrated in Figure appx-1.10.

If the structure is new or the command is save-as, the module first asks for an indicative name for the structure. If the name exists in the database, it informs the user about the duplicity and asks for another name. upon accepting the name, it then collects course date, wales data, color data and structural data from the temporary memory. If there is any error while converting data from temporary memory to a format defined for database, it will generate error message and stop the execution. Otherwise, it will save the design data to the database and finally update the library combo so that the new design comes available.

If the command by the user is ‘delete’, the module takes the confirmation from the user whether he really wants to delete the design on the canvas, or it was a command by mistake. If the user confirms the command, the module deletes related data from the database and updates the design library so that the name does not appear in the list. The deletion is one way meaning that, if a design is deleted, it can’t be restored because, the canvas is refreshed instantly.

3.3.2.9. The Load from Library Module

This module handles loading design elements from database and combine them to produce a previously saved design as it was. The elements include as shown in Figure appx-1.11, course and wales data, color data, structural data and needle data. When a design is saved, the total information needed to regenerate the same structure is split into these four elements.

The module depends on library combo to load first. If the combo is loaded and the user clicks on any name of the list in the combo, this module comes into action and loads the said elements against the selected name. upon loading the elements, if there occurs any error, it generates error message. If no error occurs in loading, it then starts converting the loaded information into translatable course data, wales data, color data and structure data into separate temporary memory cells.

The next step is calling several sub modules to convert these data into graphical representation so that the notation diagram with all the specification shows up on the screen. For generating the canvas, it calls 'Generate Canvas' sub module. Similarly, it calls 'Draw Graph' sub module for drawing the graph paper and 'Generate NeedleBed' sub module for putting needle marks on each cell in the graph paper. These three sub module takes input from course data and wales data. 'Color palette' module transforms the retrieved digits from database into color. It first defines the size and number of cells of the color palette along with its location. Then it starts converting each set of color digits into RGB component and sets the color into specified cell of the color palette. The 'Generate Structure' sub module is liable to convert the specified digits into graphical notations and place those notations in specified cells on the graph paper of the canvas. Since any displacement of a notation can cause distortion of the notation diagram or the structural design, therefore, reading and converting digits and placing the notation on the graph paper is done sequentially. Upon completion of the execution of each sub modules, the previously saved structural design with assigned color is regenerated on the screen.

3.3.2.10. The Module for Generating Structure from Library

This module converts retrieved codes to notation diagram with color combination. When a saved design is called by library, the library module loads course and wales data, structure codes and color codes. This module splits those codes into necessary portion in the temporary memory and then converts them of interpretable notation sequentially.

The module operates with several reiterative loops. It first takes the first color code and converts it to RGB component, reproduces the color and sets this color as active color for active course which starts with one. Then it reads first character in the structure. If the character is '1', it draws a face knit loop in the (Course_No, Walses_No) location with the active color. If the read character from the structure is '2', it draws a tuck loop or if the character is '3', it draws float or miss loop in the location. After drawing the loop, it updates its drawing location with incremental wales. With each increment, it first checks if the wales_no is greater than total wales in the structure. If the wales_no is yet to exceed the total wales in the structure, it goes for reading next structural character, draws the notation and the cycle repeats the same way.

If the current walse_no exceeds the total number of wales in the structure, the control goes to next course as shown in Figure appx-1.12, sets wales_no to one. It at the same time reads the color codes matching with the course number and updates the active color. The control again starts drawing notation with active color with incremental wales number until again it reaches total number of wales. Whenever the current wales_no exceeds the number of total wales, wales_no is reset to one and the control goes to new course. When active course_no exceeds the total number of courses in the structure, the loop stops. The notation graphics is then refreshed to update the screen view and the system is ready for further modification or validation for machine setup or simulation works.

3.3.2.11. The Modification Module

This module offers each kind of possible modification in the structure either newly developed or loaded from the library by tracing mouse action. The toolbar above the canvas has all the necessary tools for modifying structure. When clicked on knit loop icon, the cursor changes to knit loop from its default shape. Similarly, the cursor changes to tuck loop shape when clicked on tuck icon and miss loop shape when clicked on miss icon. Clicking on color picker icon will activate color picking module and the cursor will change to color picker shape whereas the bucket shape indicates that color filling module is activated. The shape of the mouse cursor indicates which action is ready for modifying the structure. Pressing 'Esc' from the keyboard or clicking on the default cursor icon brings back the cursor to its default shape meaning that no module is active at this moment.

As shown in Figure appx-1.13, if clicked on canvas, at first the module identifies which module is active. If clicked with knit_cursor, the module finds out the address of the cell clicked and changes the related value to that cell to '1' meaning that this cell contains knit loop. Similarly, if clicked with tuck_cursor, it changes the value to '2', and if clicked with miss_cursor the value is changed to '3' at that cell. It then calls the loop drawing module to delete the old loop and draw the newly assigned loop at that location. If clicked with eraser_cursor, the module initiates deleting module to delete the existing loop and binds '0' as values for that cell.

If clicked on color palette on the left side of the canvas, if identifies the type of action to be executed depending upon the active module. If clicked with default cursor, it opens the color dialogue box allowing the user to choose any color. If the user chooses any color and clicks 'Ok', the active color on that particular cell is updated to selected color and the related course's color is instantly changed. If clicked with color picker cursor, the color picking module gets activated, picks the current color of the clicked cell and makes it active color for the filler module. If clicked with filler_cursor, the clicked cell and related course gets updated with the active color of the filler.

If dragging action occurs with left mouse button pressed, the module takes it as selection action and draws a temporary marching ant rectangle to indicate the area selected. Upon selection, the context menu offers cut, copy, delete or paste action which is handy for users to perform repetitive works quickly. Upon paste command, the system calculates the area of the selected portion and the area marked for the paste. If the target area is smaller than the clipboard area, the system generates an error message and discards the pasting action. Each of the changes is instantly saved in the temporary memory which upon saving, get updated in the database.

3.3.2.12. The Dimension Validation Module

An active canvas may have many rows and columns which offers extra space for the designer when he develops the structural design. But in reality, the designer may not use the whole space, therefore, most of the cells may remain unused. For further processing works on the structure, it is essential to know the exact area the designer has used so that the processing time remains minimum for the computer. This module calculates the exact area the designer has used and makes the next processes execute only on this calculated area of the canvas and thereby saves resource consumption.

Each cell on the canvas has a background value, thereby, each course also has a value. This module, upon loading, at first checks the value of each course. If the numerical value of a row is not greater than ‘0’, the system takes it as an empty row having no loop in any of its cells. If the value is greater than ‘0’ it adds it to usable course and this way, as shown in Figure appx-1.14, it calculates total number of structurally significant course on the canvas. At the same time, it also stores address of the first course and last course in separate variable.

For each real course, it then takes the address of first loop and last loop and compare with initially set first loop variable and last loop variable. If the cell address value of first loop variable is greater than the address value of first loop of current course then, the first loop variable is updated with the new cell address value. Similarly, if the address value of last loop variable is less than the last loop cell address value of current course, then the last loop variable is updated with current one. Otherwise, the values are kept unchanged.

Finally, by combining the first course address, last course address, first loop address and last loop address, the system identifies the rectangle of the used cells and considers it as the active area in the canvas. All the further calculation like structure validation, repeat identification, machine setup and simulation array execution are accomplished only on this active area.

3.3.2.13. The Structure Validation Module

When designing a big structural design, it may happen that there remains some holes or missing loops. In that case, the machine setup module or simulation module can't work precisely. That is why, it is essential to check the structure for any kind of missing loops or holes and this module does that work.

Upon loading, this module collects the active area definition form the previous module and starts from the starting cell address as shown in Figure appx-1.15. It sequentially checks each cell in the active design area for '0' as the background value. If it finds any '0' within the active area, it instantly generates an error message informing that the structure has missing loops and it can't be processed further. If cell values are greater than '0' then the structure is passed forward for further processing.

3.3.2.14. The Machine Setup Module

Keeping pace with the innovations in technologies, knitting machines are also changing offering various types of facilities but the basic principle is same. For a particular design, the technician selects appropriate machine considering machine diameter and machine gauge. The next thing is to arrange the cam sets and needles in the machine to produce the designed fabric. As previously discussed, there is a knowledge gap between the designer and the technician about the machine's capability of producing the designed fabric. Most of the circular knitting machine can offer four tracks of cams. If a design exceeds this limit, the fabric can't be produced in that machine. The purpose of this module is to calculate how many tracks in the machine is required to produce the design and at same time, what would be the minimal setup of cams and needle arrangement in the machine.

Upon initiation of the module, as shown in Figure appx-1.16, it first calls the dimension validation module to identify the active design area on the canvas. If no error occurs, it then calls structure validation module to check whether there is any hole in the structure. If it passes, it then calculates course repeat and wales repeat and by combining both, it identifies the design repeat. This design repeat is then converted to cam codes and needle codes for optimization. The cams notation is then displayed with usual system as ‘K’ for knit cam, ‘T’ for tuck cam and ‘M’ for miss cam. The needle arrangement is shown with numerical numbering like /1,2,3,4/ which means, the needles in the tricks should be placed maintaining the shown serial. Other than the optimized setup, the system also shows linear setup so that the technician can use any of the two considering the time savings.

3.3.2.15. The Simulation Array Module

For converting notation diagram into virtual fabric with color combination, a set of preparatory jobs have to be done. These jobs include identification of simulation repeat, simulation repeat height and width, simulation dimension, simulation color repeat, Y axis of each course in the simulation and finally the dimension of the simulated view. This module as shown in Figure appx-1.17, performs all these jobs as prerequisite of the simulation.

Upon initiation of the simulation action, this module is called automatically and it, at first collects structural repeat data from the previous module. At the same time, it calculates geometric parameters like loop height, loop weight and yarn diameter from the geometric model using default stitch length, machine gauge and yarn count. From the loop height and loop width, it calculates simulation cell height and simulation cell width. Using simulation cell width and height, and structural repeat, it then calculates simulation repeat height and simulation repeat width. By combining these data with the screen resolution, it then calculates the dimension of the simulation window and number of simulation repeat required to build up total simulation.

Form the simulation dimension, it calculates total number of courses required and their corresponding colors. Therefore, it prepares a color array with required colors for each course. The next thing is to get Y axis of each course and save them to another array to exactly place the loops in the simulation window. Upon completion of axis array, it then reads each loop in a simulation wale and creates a string set. It then scans the prepared string set for knit loop and if a knit loop is found it checks whether it is merely a knit loop or it is a held loop by calculating number of skipped courses or held value held value (HV) before the knock-off. If HV>0, it means the current loop is not a knit loop, rather it is a held loop and it rewrites the array marking the loop as held loop.

In the same way it identifies the tuck loops and checks whether it is a regular tuck without any skipped course before knocking off or the tuck was held for skipping any course. For tracing out the yarn path of each loop, several point locations need to be defined. If the loop type is knit loop and HV=0, the module identifies it as regular knit loop and defines it starting axis, head axis and then right leg's ending axis which is again the starting axis of the next wale's yarn. If the loop type is knit and HV>0, the module first defines its starting point and then with HV, it calculates the height of the loop and the head point. Finally, it defines the right leg's ending point. If the loop is tuck, it defines the starting point and the crown point. For miss loop, it only defines starting point.

When one wale in the simulation repeat is finished the array module then goes for the second wale and the same cycle starts again and the process continues until it completes the last wale in the repeat. This way, a color array containing all the colors sequentially for the courses in the simulation, a knit or held loop list with exact axis of ending point and HV, a connection list for tuck loops with HV and ending point, and a connection list for miss loop with starting point are prepared and delivered to the actual simulation engine for drawing the visuals of the fabric.

3.3.2.16. The Face Simulation Module

All the single jersey fabrics have distinguishable two sides namely technical face and technical back. The internal side of a garment is technical back and the visible side is technical face. Except single jersey, imbalanced rib and interlock also have distinguishable face and back and most of the structural design works are carried out on the face side. When observed from the face side, the connecting yarns or floats lie on the back side of the fabric and actual loops like knit or held are visible on the face side. For simulating the structure, the module, upon loading initiates a bitmap graphics with smoothing mode keeping on.

As illustrated in Figure appx-1.18, the module first reads connection list prepared by the array module and reads the first value in the list. Depending on the course number, it collects color code from the color list for that particular course and convert it to RGB component and also collects the loop axis from the axis array. It then collects yarn diameter from the geometric model and detects the connection type.

If the current connection type if ‘float’ it calls float loop module to draw the loop. If the connection type is ‘tuck’, it calls the tuck loop module with HV and the left leg of the tuck loop is drawn in the simulation graphics. After each drawing, the module updates the end point of each connection as the starting point for the next connection. It then checks for the next connection in the connection list and the cycle continues until it reads and draws the last connection in the list.

After drawing all the connections, the module goes for simulation loop list to draw knit or held loops. Like the previous working cycle, it first reads one background character that denotes the loop type and collects the RGB value from the color code against current course from the color list. It then reads HV and yarn diameter from the geometric model. If HV equals ‘’0, it calls knit loop module and if HV > ‘0’, it calls the held loop module to draw the loop on the simulation graphics.

The process loop continues until it finishes the last character in the loop list and finally the simulation graphics is refreshed and shown on the screen as the demonstration of the designed fabric. Since the simulation starts with calling the module, initially it loads with predefined machine gauge, yarn count and stitch length. When the simulation is displayed on the screen, it offers the user to change parameters according to needs and update the simulation to fit. The user can change the zoom level with mouse wheel to have a better look. For producing electronic sample for faster communication with the buyer, the module also offers saving the current view with existing zoom level to image file with jpeg format.

3.3.2.17. The Back Simulation Module

The back simulation module creates a visual representation of the designed structure's technical back. The module first reads the simulation loop list to draw knit or held loops, as shown in Figure appx-1.19. It reads the loop type characters and compares the RGB value from the color code to the current course in the color list. The geometric model is then used to calculate HV and yarn diameter. If HV is equal to zero, the knit loop module is called, and if HV is greater than zero, the held loop module is called to draw the loop on the simulation graphics.

It then goes to the connection list prepared by the array module and reads the first value in the list after drawing all the loops. It collects color code from the color list for that particular course and converts it to RGB component, as well as the loop axis from the axis array, based on the course number. The geometric model's yarn diameter is then collected, and the connection type is determined. If the current connection type is 'float,' the loop is drawn using the float loop module. The tuck loop module with HV is called if the connection type is 'tuck,' and the left leg of the tuck loop is drawn in the simulation graphics. The module updates the end point of each connection as the starting point for the next connection after each drawing. It then checks for the next connection in the connection list, and the cycle repeats until the last connection in the list is read and drawn.

The process loop continues until the last character in the loop list has been completed, at which point the simulation graphics are refreshed and displayed on the screen as a demonstration of the designed fabric. The simulation loads with predefined machine gauge, yarn count, and stitch length because it starts with calling the module. When the simulation is displayed on the screen, the user has the option to change parameters and update the simulation to fit their needs. To get a better look, the user can use the mouse wheel to change the zoom level. The module also allows you to save the current view with the current zoom level to an image file in the jpeg format for faster communication with the buyer.

3.3.2.18. Module for Modifying Simulation

As previously stated, the simulation module generates the visuals with predefined machine gauge, yarn count, and stitch length on its initial loading. A sliding panel has been added to the right side of the simulation window to assist the designer in changing the parameters. This panel contains the necessary parameter changing and updating functionality. The designer can easily change a parameter in that location and then refresh the view to see how the parameters affect the fabric.

As shown in Figure appx-1.20, when this module is loaded, it reads the user's input for machine gauge, yarn count, and stitch length, among other things. In conjunction with the geometric model, it then determines whether the yarn produces yarn jamming in either the width or the height direction for the given stitch length, depending on the direction of the jamming. If jamming occurs, an error message is generated, and the user is instructed to modify the inputs. Following the receipt of appropriate inputs, it calculates the determinant of the equations for real values and converts the count to yarn diameter using the formulae provided. It then converts the cell height, cell width, and yarn diameter to the appropriate pixel size and calls the simulation array module to reconstruct the parameter arrays. Figure appx-1.17

illustrates how the array module calls the face simulation module or the back simulation module at the conclusion of its execution, depending on which simulation type has been selected. The simulation module re-renders the visuals on the screen with the parameters that have been changed.

The simulation window is equipped with a context menu, which appears when the right mouse button is pressed on the simulation window in question. It allows the user to switch from face simulation to back simulation, change the background color, and save the current view. The zoom option allows to zoom in and out of the view from 0 to 400 percent without losing any pixels, ensuring that the image remains clear and free of distortion.

3.3.3. The Rib Module

Knit fabric in the form of rib is the second most common knit fabric type produced on a double jersey machine. The machine can be either circular or straight in shape frequently referred to as a Vee Bed machine. Irrespective of the shape, the machine has two sets of needles and two sets of cams. The needles are placed in an alternate gating arrangement, and the loops are also subsequently created in alternative manner from one bed to another which allows for greater fabric extensibility in the breadth direction. The product extends from a simple 1×1 rib to thousands of variations, ranging from very fine gauge to very coarse knitwear.

3.3.3.1. The Architecture of the Module

The rib module is composed of several child module which in collaboration bring out the intended job associated with plain rib and derivatives. The modules as shown in Figure 3.8 are design module, storage module, library module, modification module, validation module, machine setup module and simulation module.

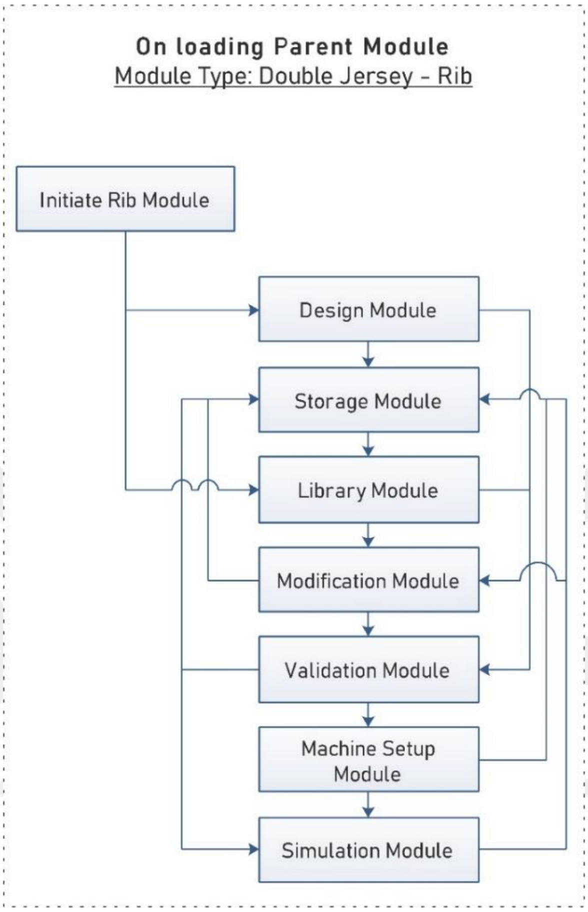


Figure 3.8. Architecture of the Rib module

The design module initiates and provides all the facility required for developing new structures, storage module accomplishes jobs associated with database updating, library module performs the jobs of calling back a structure from database, modification module traces all changes brought out, validation module identifies structural dimension and checks for any hole in the structure area. The machine setup module calculates required needle arrangement and cam setup for producing the design in the machine. Finally, the simulation module simulates the fabric from the given notation diagram.

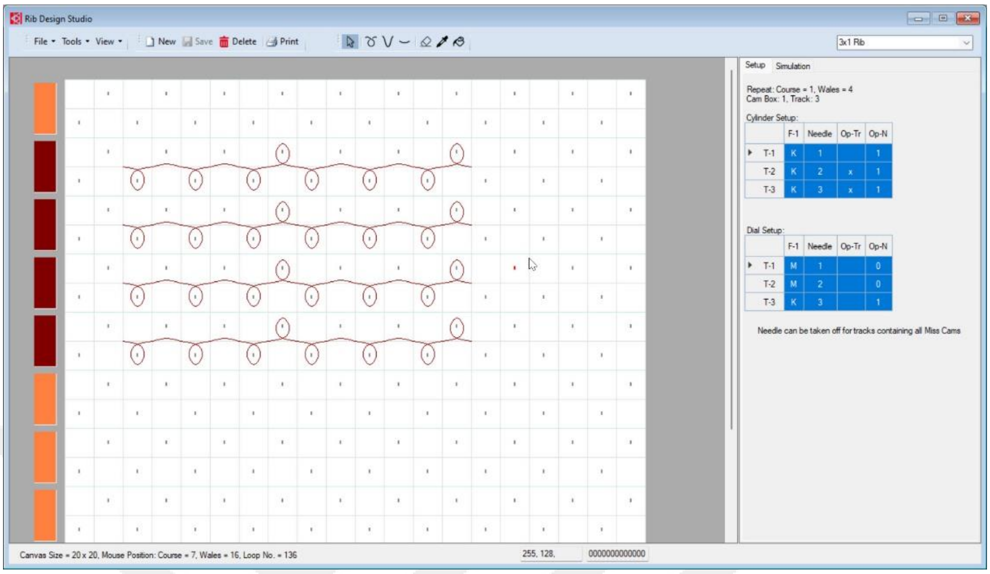


Figure 3.9. The development interface of Rib module

Each of the child module is again composed of many supporting modules which work in association of each other. The general sequence of the developing work is to develop notation diagram, assign colors, save to database, bring out changes if required, validate the structure against machine parameters, identify the setup parameters and view virtual fabric. If required, user can move from module to module to suit his development works like simulation to modification, simulation to storage, validation to simulation or validation to storage etc.

The interface of the development environment has been kept as simple as the single jersey module discussed in the previous section. The main interface of this module has been shown in Figure 3.9. The main design area is composed of a canvas and graph with needle marks matching with rib machine gating. On the left side of the canvas, the color palette has been provided. At the top of the window, required notation tools like knit, tuck and miss tool, color tools, save, edit or new document tools have been added. The right-side panel shows the necessary needle arrangement and cam setup information and at the top right corner, the library combo has been added offering the access of saved design in the database.

3.3.3.2. The Design Module

The design module is composed of child modules like canvas setting, graph paper, needle gating, color palette and notation modules. The working procedure has been shown in Figure appx-1.21. Upon initiation of the module, it loads with predefined number of course and wales. If there is input errors, it triggers error message, otherwise it goes for generating the graph paper as instructed. Unlike single jersey, rib is produced with two sets of needles and the needle module comes up here to emulate the rib gating with default 1×1 plain rib setting. The system then prepares the color palette with default active color which the user can change as wish. The notation module loads at the end to provide functionality of each development tools that the user may require in developing the notation diagram or assigning colors to courses. Finally, the file handling module loads at the background to offer transferring data from canvas to database or from database to canvas.

3.3.3.3. The Canvas Module

The canvas is the space dedicated to hold the graph paper and needle emulation matching with rib machine. Upon initiation of rib module, this sub module loads with default values. If the user tends to modify the size of the canvas, he can invoke the 'New' canvas which will ask for number of course, number of wales and cell size of the graph paper. Since two rows on the graph paper makes one course of rib fabric, thereby, it is essential that the number of course is even. If the user inputs an odd number the system adds one to it and makes the input even. As shown in Figure appx-1.22, It then calculates height and width of the canvas required to meet the user demand and sends the processed parameters to graph module. In the meantime, it also initiates notation bitmap and notation graphics to hold the graph and further development of notations.

3.3.3.4. The Graph Module

The graph module reads canvas width, canvas height and cell size from the canvas module and takes predefined color for drawing pen and marking pen. As illustrated in Figure appx-1.23, it then draws vertical lines across the canvas width at a distance equal to cell height. When vertical lines are drawn it then goes to draw horizontal lines across the height of the canvas. Since two rows on the canvas corresponds to one rib course, the system uses marker pen instead of the drawing pen to draw with different color at every even rows so that the user can easily identify and distinguish the rows' correspondence to courses. It then updates the notation graphics and refreshes the notation bitmap to show the graph on the screen and calls the needle module to draw the needles.

3.3.3.5. The Needle Bed Module

The two set needles in a rib knitting machine are placed in a way that they operate in between each other without face-to-face collision. One set is liable to produce face loops on the technical face of the fabric whereas another set produces loops for technical back from the same yarn in a course. In other words, the yarn moves from cylinder needles to dial needles sequentially. Both the sets of needles are operated by separate cam sets located in cylinder and dial.

The needle bed module upon its initiation reads number of cells in width and height direction on the graph paper and considers each cell as a loop place. Since, alternate needle gating is required it blocks odd cells on odd rows and even cells on even rows and leaves them empty to comply with rib knitting machine. As shown in Figure appx-1.24, the algorithm checks if it finds a cell address with odd position in odd rows it skips, otherwise it places a needle mark on the cell. In the same way it checks if a cell address in even in the even rows and skips it. Otherwise, it denotes the cell as usable and places needle mark on it.

3.3.3.6. The Color Palette Module

All the odd rows on the graph paper corresponds to the dial courses whereas all the even rows on the graph paper denotes cylinder courses. And actual course in the rib fabric is formed by combining one dial and one cylinder course or one odd and one even row on the graph paper. Therefore, the actual number of courses in the fabric is half of the number of rows on the graph paper and number of color cells on the canvas is half of the rows meaning that, a single color cell provides color to two rows on the canvas. Each two rows, in combination in the actual fabric will produce a single course.

As shown in Figure appx-1.25, the module reads cell dimension and the number of rows on the graph paper. It then calculates the height and width of the color palette and finalizes its location on the left side of the canvas. The filling brush is initiated with predefined color on first loading and the module starts drawing interactive color cells on the color palette one for each two rows until it reaches the end of the canvas. Each color cell responds with users' interaction and opens windows' color dialogue with full color range that windows can offer so that the user can change and set colors for each cells according to their choice. In the color dialogue the user can define new color by changing hue, chroma or saturation or by changing RGB values so that it meets his requirements. Upon accepting the color, it instantly replaces the predefined color on the active color cell and makes the new color as active. On changing any active color on any color cell on the color palette, it instantly changes the color of the loop notation in the respective course. The next thing is to allocate temporary memory for tracking changes of colors on the canvas. The module reads the color values of each color cell on the color palette and temporarily stores them with proper cell address.

Upon changing any color in the color palette, it instantly updates this temporary color codes ready to be sent to database upon saving or regenerate colors from these color values upon requirements. For precisely cloning a color from one cell on the color palette to another cell, ‘color picker’ and ‘color filling’ tools work in association with the color palette to make the work easy for the users.

3.3.3.7. The Notation Module

Each of the active cell on the graph paper of the canvas requires a value to indicate whether the cell has a loop notation or not. Upon first loading, the cells corelate to a predefined value. To set the predefined value, the module reads number of courses and wales and calculates number of cells. As shown in Figure appx-1.26, it then appends notation value of each cell to a temporary memory and makes it ready to for the modification module or sending it to database upon saving.

3.3.3.8. The Storage Module

As illustrated in Figure appx-1.27, this module is responsible for saving new designs, updating and saving existing designs, renaming and saving existing designs, and completely deleting existing designs from the database. It is not necessary for the canvas to have any loop notation in order to save a design; an empty canvas can also be saved with a unique name. It is designed in this manner for the designer's convenience.

When the user invokes the 'Save' or 'Save as' action, the module prompts the user for a name and verifies that the name already exists in the database. If the name already exists, the user is notified and asked to choose another. After obtaining a unique name, it populates the canvas with course, wales, color, and loop data and sends them to the database. After a successful save, the library combo is updated to include the name in the design list. If the design is not new and the command type is 'Save,' the module considers the work to be a modification work and from temporary memory, it reads all changes made to colors, loop notation, and so on, and prepares the change of data set in the prescribed format. It then establishes a database connection and updates the database with each update.

It is possible for the user to intend to delete an entire design from the database. If the command type is 'Delete,' the module prompts the user to confirm whether he truly intends to delete the active design or whether the command was called accidentally. If the user responds positively, the module establishes a connection to the database and deletes the design. Simultaneously, it updates the design list in the library combo, removing the deleted name from the list.

3.3.3.9. The Recall Database Module

Recalling a saved structure is invoked by selecting the desired design from the drop-down library combo. Whenever a structure name is changed in the library combo, this module interprets the action as calling the saved structure from the library and loads respective data set from the database. It then converts the dataset to course data, wales data, color data and structure data. Finally, as shown in Figure appx-1.28, it calls the canvas module and graph module to prepare the canvas and needle, color palette and structure module to regenerate the structure on the screen.

3.3.3.10. The Structure Generation Module

The structure generation module is in charge of tasks such as converting saved data to a visual notation diagram that can be viewed on the screen. It is self-initiated following the 'Recall' module and, as illustrated in Figure appx-1.29, reads the structure code, course and wales data, as well as the color codes prepared by the previous module. It sequentially reads each notation code and invokes the appropriate loop drawing module for cylinder or dial.

If the read loop character is '1', it invokes the cylinder knit loop module; if the read loop character is '2', it invokes the cylinder tuck loop module; and if the read loop character is '3', it invokes the cylinder float loop module. The internally called module then comes into action and draws one required loop on the canvas with defined parameters. The character value ranges from 1 to 3 in the single jersey module, but rib fabrics also use a second needle bed. As a result, the value ranges between 1 and 6. When the loop character is '4', the dial knit loop module is invoked; when the denoting value is '5', the dial tuck module is invoked; and when the current character is '6', the dial float module is invoked to draw back float. When a course is completed, the control advances to the next and so on until all courses retrieved from the database are displayed on the canvas.

Prior to loading of this module, the color palette module prepares color data for each course. Before going to draw any loop, the loop address is synchronized with the canvas's graph paper's cell address. Additionally, it retrieves color data from the palette module and draws the active loop with the specified color. As previously stated, the double jersey canvas features alternate cells that lack both the needle mark and any loop. This is to simulate the needle gating of a real-world rib machine.

After successfully drawing the complete notation diagram of the structure on the canvas, the module scans all cells of the graph paper that lack a needle mark. It then denotes each of these cells as inactive, preventing the user from intentionally or accidentally inserting a loop onto them.

3.3.3.11. The Modification Module

This module is responsible for displaying changes in notation and color as intended by the designer and for tracking each change for database updates. It interprets the user's mouse clicks on the canvas or color palette and acts accordingly.

The interface contains the necessary toolset, activating any of which changes the cursor to resemble that tool and activates the associated sub module. When the designer uses any notation tool to click on the canvas, it first determines the type of action the user desires. It then determines the precise location of the user's click. When an even course is clicked and the tool is 'Knit loop,' a face or cylinder knit loop is placed on the clicked cell. If the clicked cell is on an odd course, a back or dial knit loop is drawn, as illustrated in Figure appx-1.30. When the user selects 'Tuck loop' from the toolset, the module inserts a face tuck loop if the clicked cell is on an even course and a back tuck loop if the clicked cell is on an odd course. Similarly, when the 'Float loop' tool is clicked, it places a face float loop on an even course or a back float loop on an odd course. Prior to inserting a loop, the system verifies that the cell is empty. If the cell is empty, the module immediately places the loop; however, if the cell is not empty, the module calls the delete loop module using the cell address to delete the existing loop and then places the new loop. If the user wishes to delete a loop himself, the system invokes the 'Delete loop' module with the cell address and deletes the loop. When the user clicks on a color palette cell, the color dialogue box is invoked, displaying the full color range that Windows can provide. When a new color is selected or a new combination is created by modifying the RGB value or hue, chroma, and saturation and confirming the system to use the color, the active color of that cell in the color palette changes instantly, as does the color of that particular course. The mouse is neutralized by pressing 'Esc' or clicking the default mouse icon on the toolbar. The temporary memory is updated instantly in response to each modification by the user, and all alterations are sent to the database when the user saves the changes.

3.3.3.12. The Validation Module

Knit fabrics can be made entirely of knit loops or a combination of knit, tuck, or miss loops, but they cannot be made without any knit loops. As a result, a structure on the screen is invalid if it lacks any knit loop. For an accurate rib structure design, the number of loops on the face side of a course must equal the number of loops on the back side, though this similarity may not be visible in real fabric due to miss loops. Again, a course in a rib structure on the canvas during design time is composed of two successive rows, which means that the number of rows used for design purposes on the canvas must be even, or there must be no unused rows within a notation diagram. Finally, a knit structure must be free of missing loops and discontinued yarns. All of these parameters are required for a valid rib structure, and as illustrated in Figure appx-1.31, this module verifies and ensures that all of these parameters are met in correct format by warning the designer about any lacks prior to further processing.

On initialization, the module begins reading each row on the canvas and optimizes by trimming the starting and ending empty cells. If the row's trimmed value equals 0, it indicates that the row is empty, without any notation, and the control advances to the next row. If the trimmed value is not 0, the row is treated as a real course by the module. It begins by reading alternate cells within the trimmed range and storing their contents in a variable. After scanning and appending all the cell values in a row to the variable, it determines whether the row is the starting course for the design. If the current row does not appear to be part of the starting course, it is considered to be part of the ending course and the ending course number is updated. It checks each cell value within the trimmed range to determine whether a yarn has been discontinued within the current row.

If a value of '0' is encountered, the module notifies the designer of discontinued yarn or missing loops in the current course and suspends further processing. If no '0' appears in the trimmed cell values, the module checks the number of cells used in the current course. If the number of cells used does not match the number of cells used in previous courses, the system generates an error message warning the designer that the course is missing loops once more. If the number of cells used in this course equals the number of cells used in the previous course, the module counts it as a real course and records the course number.

Once all rows have been read and validated, the module compares the actual courses stored in the course counter variable to the calculated actual courses from the starting and ending course numbers. If the result does not appear to be equal, the notation diagram contains one or more empty rows, and the system generates an error message. The next step is to determine whether the notation began with any of the odd rows. This is critical because the widely accepted rule for notation diagrams is that dial loops should be arranged in odd rows. As a result, if the starting row is not an odd row, the system displays an error message requesting modification. Finally, to adhere to two canvas rows with one actual course in the fabric, the module checks number of rows used for design purposes. If the total number of rows used is even, the development is considered valid.

3.3.3.13. The Repeat Detection Module

The detection of structural repeat is critical because the cam setup, needle arrangement, and fabric simulation are all dependent on structural repeat. As illustrated in Figure appx-1.32, this module calculates the structural repeat of rib fabric based on the notation diagram developed on the canvas by the designer. The canvas begins with a dial course in accordance with standard procedure, but for convenience, this module appends the code for each odd row to the code for each even row during repeat calculation. In other words, it starts with an actual cylinder row and then adds the corresponding dial row to match the arrangement in the actual fabric, resulting in a fused course code.

The module then calculates all the real factors of the total number of combined courses. Assume that the initial factor is 'f'. The module then reads the 'f' number of fused course codes and compares them to the total fused course code in block mode. If the block matches and the number of matches equals the active factor, the block is confirmed as a course repeat and the matching routine is terminated. Otherwise, it continues the matching routine, moves on to the second factor, and performs the same checks. The routine continues until the final factor is checked. If the block matching fails for all factors, it informs the designer that the developed structure is not a true repeat and thus the total design area is a repeat. In the similar, the module calculates wales repeat.

3.3.3.14. The Machine Setup Module

The machine setup module's purpose is to ensure that the designed structure is machine-producible. This module analyzes the structure and displays the appropriate cam setup and related needle arrangement either in linear mode or in optimized mode, allowing the designer to determine whether the structure can be manufactured on his factory's existing machine facility and facilitates the technician to select the optimal setup for him.

The module accepts input from the preceding module, which identifies structural repeats in the notation diagram and the repeat block on the canvas. It internally converts the rows to columns from the repeat block and saves the rearranged notation codes in a variable named 'WalesText'. It then creates two extra variables, as illustrated in Figure appx-1.33, to store the cylinder and dial notation codes separately, and begins reading each character from the WalesText. If the character corresponds to a dial, the code is appended with 'DialCamText'; if the character corresponds to a cylinder loop, the code is appended with 'CylCamText'.

When the preparation of 'CylCamText' and 'DialCamText' is complete, it converts the codes to cam notation and calculates linear cam setup for both cylinder and dial in accordance with notation and practice in the factory. To optimize the cam setup, the module extracts a block from 'CylCamText' that corresponds to the course repeat and compares it to the rest of the codes. If any matches are found, it replaces the duplicate match and proceeds to the next block until all codes in the 'CylCamText' are completed. Finally, it assigns an equivalent needle to the discovered duplication and deletes the cam code.

This results in a concise cam code with the fewest possible tracks and needle types, which is equivalent to a linear cam setup. The 'DialCamText' is also analyzed in the similar manner in order to determine the optimal optimization. After optimizing the dial and cylinder setups, the information panel on the right side of the canvas displays the equivalent cam and needle notations.

3.3.3.15. The Simulation Array Module

Prior to beginning the simulation, this module generates a several number of arrays and lists from the structure and color palette. In addition to the color codes the prerequisite includes a yarn path for each course which is composed of a cylinder loop list, a cylinder connection list, a cylinder to dial transfer list, a dial loop list, and dial connection list.

When the module is loaded, as illustrated in Figure appx-1.34, it reads the default stitch length, machine gauge, and yarn count from which it calculates the dimensions of the simulation window in accordance with the screen resolution. Additionally, it calculates the number of courses and wales required to fill the simulation dimension by utilizing the geometric model's cell height and width coming from stitch length and machine gauge. To create the color list, it first determines the number of colors used by the designer on the canvas and then populates it with the used colors sequentially and, if necessary, with multiple repeats of colors.

For loop list, it begins by identifying the cylinder courses within the structural repeat detected by the previous module. It then begins reading each character in the cylinder course's notation. If the notation character is '1', which indicates that the current loop is a cylinder knit, the loop is added to the loop list. While adding the loop to the loop list, it evaluates the held value HV to determine whether the loop is a pure knit loop or a held loop. If HV is greater than 0, the loop is considered to have deviated from its normal knock-off course, and thus is a held loop. It augments the loop parameter with the HV value.

Each loop is added to the loop list with the appropriate axis point parameter, which enables the loop to be drawn in the simulation window at the desired location. Apart from knitted and held loops, all other loops are treated as yarn connections and are added to the connection list with the appropriate axis point. After completing the cylinder loops and connect lists, the module proceeds to the dial loop and connect lists in the similar fashion.

3.3.3.16. The Face Simulation Module

The simulation of double jersey fabric consists of four layers: dial loops, dial yarn paths, cylinder yarn paths, and finally cylinder loops. As illustrated in Figure appx-1.35, the module initiates simulation graphics and a simulation bitmap upon loading in order to store and represent the visual simulation on the screen. If the designer chooses face simulation, the module begins with the dial loop list and reads each loop value in the list sequentially. If the value of the loop is 4, it checks to see if HV is greater than zero. When HV equals zero, the control invokes the knit loop module. If HV is greater than zero, the control invokes the held loop module, which draws the loop on the simulation window. The knit loop or held loop module draws the loop with the appropriate axis value and required color information from the color list. The course skip value is derived from the HV. The process is repeated until all loops in the dial loop list are read.

For the dial connection path, the control begins by reading the dial connection list, which contains information about the connection type and axis. If the connection type is miss, the module invokes the float loop sub-module to draw the float loop in the simulation window. The color list is used to provide color information. The tuck loop module is invoked to draw the loop if the loop type is tuck. Because yarn can migrate from one loop to another within the same needle bed without going from cylinder to dial in the design work, the yarn path simulation has been kept in a separate connection list.

Following completion of the dial yarn path, the control returns to the cylinder connection list and draws the yarn path on the screen in the same manner as it did with the dial connection list. As the final layer, the module switches to the cylinder loop list and, as stated previously, resets its active color to its default value and collects new color information from the color list, synchronizing the current loop in the cylinder loop list the same way it did for dial loops. When the four layers have been drawn, the control refreshes the simulation graphics, displaying the changes on the screen.

3.3.3.17. The Back Simulation Module

The back simulation module displays the technical back of the fabric, allowing the designer to see how the fabric looks from the back. It operates similarly to the face simulation module, except that the layers are rendered in reverse order. It simulates cylinder loops first, followed by cylinder yarn paths and dial yarn paths, and finally dial loops, as illustrated in Figure appx-1.36. Both modules allow for customizing the simulation window's background color and saving the screen image for use as an electronic sample with a zoom level of up to 400 percent.

3.3.4. The Interlock Module

Interlock fabrics are considered as a combination of two rib courses with a face-to-face loop arrangement in which the loop on the face side is exactly opposite the loop on the back side; the needles in the bed are also face-to-face. When the machine is running, the face-to-face needle set ensures that neither needle engages at the same feeder at the same time, preventing a collision. Two simple rules govern the mechanism:

a. For each feeder, the cam arrangement in the dial and cylinder must be such that only long set or only short set needles are activated. The setup must prevent a single feeder from simultaneously advancing both the short set and long set needles into action.
b. A short needle must lie opposite the long needle. In an aligned tract or face-to-face trick in dial and cylinder, if one needle is from short set, the opposite trick must hold long set and vice versa.

3.3.4.1. Design Variation in Interlock

A designer can design interlock fabric by infinite combination of knit, tuck and miss loops or color variation in yarns. Each loop combination produces a different structural design which with yarn variation can generate further deviation. The variation in designs is sometimes for aesthetic purpose or sometimes for decorative purpose. The technician in the production site is responsible to convert the structural design into actual fabric by choosing appropriate materials and altering machine setup. A design variation in interlock fabric can be brought out by altering only needle arrangement, altering only cam arrangement, altering both needle and cam arrangement, altering some cams in particular tracks, and using variation in yarns.

3.3.4.1.(1). By Altering Only Needles

New structural designs can be produced in an interlock machine by altering needle types but keeping cam arrangements unchanged. In this case, the only rule for interlock machine setup is to ensure short needle against long needle sets. The following setup shown in Table 3.3 illustrates a plain interlock machine setup to be converted to produce an interlock derivative by altering needle in second and fifth tricks.

Table 3.3. Design variation by altering needles

Plain Interlock Setup	Dial	Needle Arrangement	S	L	S	L	S	L	S	L
		Long Needle Track	K	M	K	M	K	M	K	M
		Short Needle Track	M	K	M	K	M	K	M	K
	Cylinder	Short Needle Track	M	K	M	K	M	K	M	K
		Long Needle Track	K	M	K	M	K	M	K	M
		Needle Arrangement	L	S	L	S	L	S	L	S
Modified setup	Dial	Needle Arrangement	S	S	S	L	L	L	S	L
		Long Needle Track	K	M	K	M	K	M	K	M
		Short Needle Track	M	K	M	K	M	K	M	K
	Cylinder	Short Needle Track	M	K	M	K	M	K	M	K
		Long Needle Track	K	M	K	M	K	M	K	M
		Needle Arrangement	L	L	L	S	S	S	L	S

[S = Short needle, L = Long needle, K = Knit cam, M = Miss cam]

3.3.4.1.(2). By Altering Cams

In contrast to bringing structural change by altering needles only, frequently changes in designs are implemented by changing or altering cams in particular tracks. This type of change can be done either in dial or in cylinder or in both the dial and cylinder tracks. Table 3.4 shows such a change in second and fifth feeders where in dial, in the second feeder, long needle has been activated instead of short needle and in cylinder, long needle has been activated instead of short needle. In the same way, in fifth feeder, short needle has been activated in dial instead of long needle and long needle has been deactivated instead of activation for structural requirements.

Table 3.4. Design variation by altering cams only

Plain Interlock Setup	Dial	Needle Arrangement	S	L	S	L	S	L	S	L
		Long Needle Track	K	M	K	M	K	M	K	M
		Short Needle Track	M	K	M	K	M	K	M	K
	Cylinder	Short Needle Track	M	K	M	K	M	K	M	K
		Long Needle Track	K	M	K	M	K	M	K	M
		Needle Arrangement	L	S	L	S	L	S	L	S
Modified setup	Dial	Needle Arrangement	S	L	S	L	S	L	S	L
		Long Needle Track	K	K	K	M	M	M	K	M
		Short Needle Track	M	M	M	K	K	K	M	K
	Cylinder	Short Needle Track	M	M	M	K	K	K	M	K
		Long Needle Track	K	K	K	M	M	M	K	M
		Needle Arrangement	L	S	L	S	L	S	L	S

[S = Short needle, L = Long needle, K = Knit cam, M = Miss cam]

3.3.4.1.(3). By Altering both Cams and Needles

For complex structural changes, sometimes it is required to change both the cams and needle arrangements. This type of change require technically sound person is primarily responsible for implementing new designs in the machine. The following Table 3.5 show changing of both needle and cam arrangement from a plain interlock setup. In the second, in the dial, long needle has been changed with short needle and fifth tricks short needle has been changed with long needle. in the cylinder, in second trick, short needle has been changed with long and in the fifth trick, long needle has been changed with short needle. To ensure the compliance with interlock machine setup rules, changes have been made in cam arrangements also keeping alignment with changes in needle arrangements.

Table 3.5. Design variation by altering both needles and cams

Plain Interlock Setup	Dial	Needle Arrangement	S	L	S	L	S	L	S	L
		Long Needle Track	K	M	K	M	K	M	K	M
		Short Needle Track	M	K	M	K	M	K	M	K
	Cylinder	Short Needle Track	M	K	M	K	M	K	M	K
		Long Needle Track	K	M	K	M	K	M	K	M
		Needle Arrangement	L	S	L	S	L	S	L	S
Modified setup	Dial	Needle Arrangement	S	S	S	L	L	L	S	L
		Long Needle Track	K	K	K	M	M	M	K	M
		Short Needle Track	M	M	M	K	K	K	M	K
	Cylinder	Short Needle Track	M	M	M	K	K	K	M	K
		Long Needle Track	K	K	K	M	M	M	K	M
		Needle Arrangement	L	L	L	S	S	S	L	S

[S = Short needle, L = Long needle, K = Knit cam, M = Miss cam]

3.3.4.1.(4). By Using Variation in Yarn

The easiest way to bring out the change in looks of fabrics is applying variation in yarns in sequence. This variation can be in count, twist, fibers, fiber combination, color of yarns. For plain interlock, sequential color change is used to produce stripe fabric. Careful selection of color combo keeping balance with structural repeat in derivatives brings out drastic change in appearance and look.

3.3.4.1.(5). By Variation in Particular Feeder

These types of changes are brought out for minor changes in structure or sometimes to keep a feeder out of action. In the following Table 3.6, from plain interlock setup, the second and fifth feeders have been brought to out of action where in the cylinder, short needle and long needle were supposed to knit.

Table 3.6. Design variation by modifying feeder action

Plain Interlock Setup	Dial	Needle Arrangement	S	L	S	L	S	L	S	L
		Long Needle Track	K	M	K	M	K	M	K	M
		Short Needle Track	M	K	M	K	M	K	M	K
	Cylinder	Short Needle Track	M	K	M	K	M	K	M	K
		Long Needle Track	K	M	K	M	K	M	K	M
		Needle Arrangement	L	S	L	S	L	S	L	S
Modified setup	Dial	Needle Arrangement	S	L	S	L	S	L	S	L
		Long Needle Track	K	M	K	M	K	M	K	M
		Short Needle Track	M	K	M	K	M	K	M	K
	Cylinder	Short Needle Track	M	M	M	K	M	K	M	K
		Long Needle Track	K	M	K	M	K	M	M	M
		Needle Arrangement	L	S	L	S	L	S	L	S

[S = Short needle, L = Long needle, K = Knit cam, M = Miss cam]

3.3.4.2. Manual Calculation of CAM Setup and Needle Arrangement

Since interlock machine is composed of two needle bed and at least two sets of different types of needles, it is a bit complex to calculate the machine setup manually and this complexity increases with the increase of structural design variation in the fabric. Therefore, one of the main purposes of this software module is to automate the calculation of cam setup and needle arrangement for permissible structural changes. Before going to automated calculation, it is necessary to explain the system of manual calculation of cam and needle arrangement since the automation is based on this manual calculation. The nature on which the system of manual calculation is based on, as illustrated in Figure 3.10, are as follows:

a. Number of course in the repeat = Number of Feeder / Cam box in the repeat
b. Number of wales in the repeat = Number of Tracks in the Cam box.

c. Always start from C1×N1 and go upward in the structure because, this is the first loop by that particular needle. As the needle moves in the Track, it produces upper loops sequentially.
d. Needle sequence in the structure is important than position of the respective Track. Track position can be changed for convenience but needle sequence if changed from structure, causes distorted design.
e. Go to left from right direction in the Track for placing cams for that particular needle. The needle hits the Cam from right side and gradually goes to left for a machine rotating clockwise.
f. If two tracks are similar, they can be merged to one for optimization.
g. For a feeder, if both cylinder and dial cam box are all Miss, yarn supply in that feeder should be stopped or Cambox/Feeder optimization can be done.
h. In interlock machine, a long needle in the cylinder must not have a long needle in the dial. They must be opposite type because, opposite two needles never knit at the same time.
i. The feeders are grouped in such a way that, one set of feeders always feeds to a certain type of needle. For plain interlock, if a set of feeder feeds to long type needle, other set will feed short type needle. The cams are arranged in such a way that both long and short needles cannot be activated at the same feeder. That is why, two rib fabric is produced which is ultimately merged to form the interlock fabric.
j. A long feeder only feeds the long needle and a short feeder feeds only short needle. Exception is avoided by cam setup.

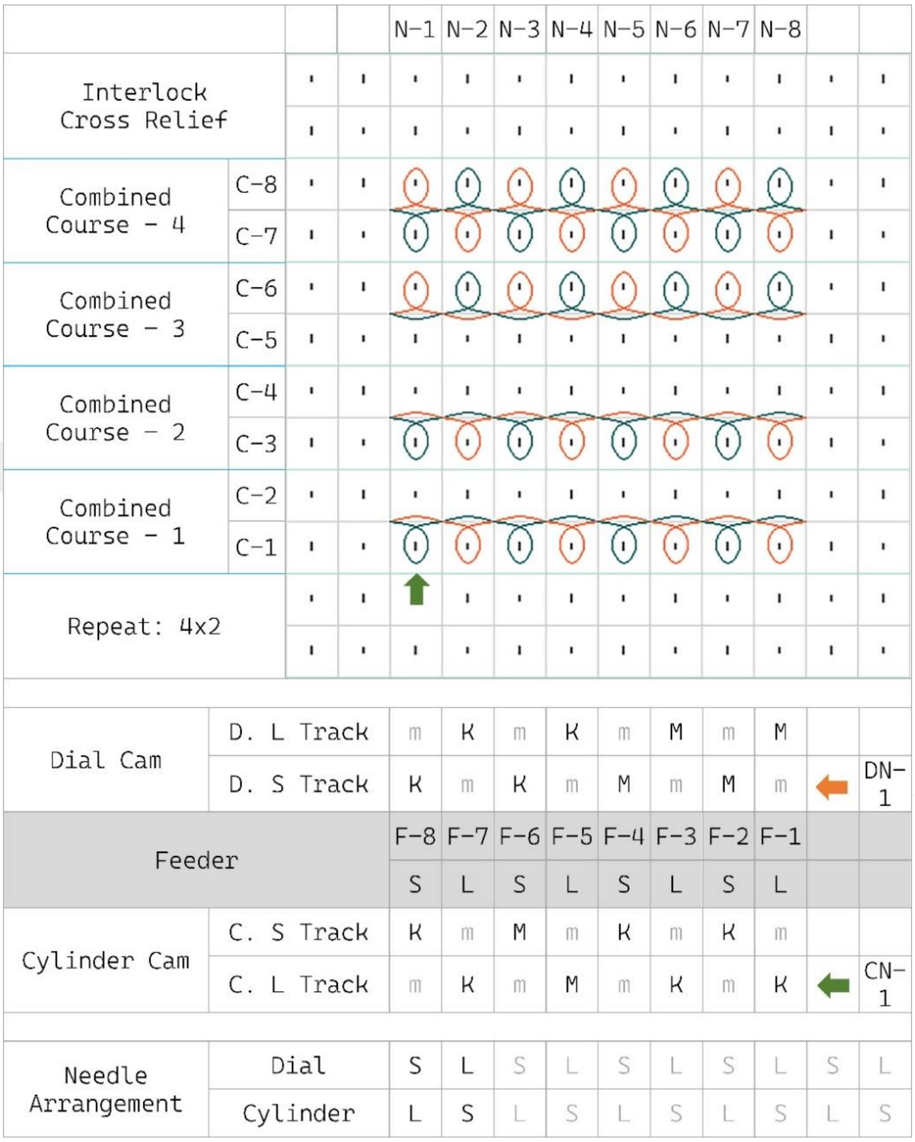


Figure 3.10. Manual calculation of cams and needles in interlock structure
[S = Short needle, L = Long needle, K = Knit cam, M, m = Miss cam]

3.3.4.3. The Architecture of the Module

The interlock module is composed of a number of child modules, including a canvas module, a graph module, a needle bed module, a notation module, a library module, and a product information module. All modules work in unison to provide the designer with the tools and information necessary to develop structural designs and color schemes for interlock fabrics. The interconnectivity of different modules has been shown in Figure appx-1.37 As illustrated in Figure 3.11, the interface is composed of a graph paper-like canvas with needle marks corresponding to the interlock gating on each cell. File management tools, notation tools, needle gating tool, and color management tools have been added to the canvas's top. A color palette with interactive color cells for each row of the graph paper has been added to the left side of the canvas.

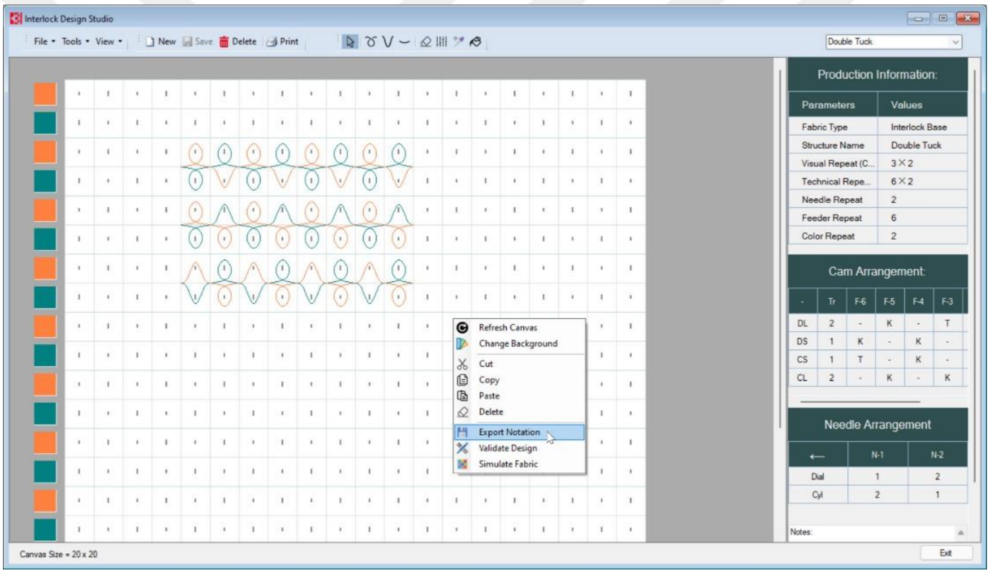


Figure 3.11. Interface of interlock module

On the right side of the canvas is a panel that displays the appropriate fabric information as well as the cam and needle configurations required for the developed structure. Above the information panel, a drop-down combo box has been added to enable access to database-stored designs. By pressing down the right button of the mouse, the designer can access a context menu from which he or she can validate the structure and determine the machine configuration.

3.3.4.4. The Canvas Module

The canvas module serves as the hub for all other modules. Upon loading, the module calculates the canvas size using the default number of courses, wales, and cell size. If the user wishes to modify the number of courses, the number of wales, or the cell size of the graph paper, he can do so by invoking the 'New Design' command, which populates an input widow ready to accept the user's inputs. As illustrated in Figure appx-1.38, the module checks all user input for negative or non-numerical values, as well as the row count. A course in an interlock fabric is made up of two yarns that move across the fabric from cylinder to dial and dial to cylinder. To facilitate development works, two rows on graph paper have been associated with one actual fabric course. As a result, the number of rows on the graph paper cannot be an odd number, as two rows constitute an interlocking course. If the number of rows from the user input is found to be an odd number, the system automatically adds one to make the number even without requesting correction from the user. If any other input error occurs, the system generates respective error message to alert the user to the error.

The notation box is the area on the graph paper that is usable for drawing loops and is made up of notation cells. The module calculates the size of the notation box and the height and width of the color palette based on the user's input of the number of rows, columns, which corresponds to the number of courses and wales in the fabric, and cell size. It is not necessary for the user to enter the exact number of rows and columns required for the design work; rather, he can enter an area large enough to accommodate an easy working environment, with some rows and columns remaining empty after the structural design is developed. Additionally, the module calculates the size of the graph container and the position of the color palette and notation box based on the parameters passed in. It then initiates the creation of notation graphics and a notation bitmap to hold and display the notation on the screen. Simultaneously, it initializes color graphics and color bitmaps and, if necessary, refreshes the color palette.

3.3.4.5. The Graph Module

On the canvas, the graph paper module defines notation cells into which loops are drawn. Each cell corresponds to a notation loop, with the appropriate address for the loop in the repeat. Because each pair of rows on the canvas corresponds to a single actual course, the graph module adds a marking line between each pair of rows to help the user easily identify the constituent rows for a course.

When the module is loaded, it first reads the canvas width, height, and cell size specified by the user and then begins drawing the graph with a default color. As illustrated in Figure appx-1.39, it changes the pen color and draws a marking line every two rows. Finally, it updates the notation graphics to display the graph on the screen and invokes the needle module to begin drawing needles in each cell.

3.3.4.6. The Needle and Needle Bed Module

As previously discussed, the needle arrangement maintains a predefined arrangement between dial and cylinder needles, with a long needle corresponding to a short needle in the opposite bed. To maintain consistency in the arrangement, this module assigns a short needle to the starting dial loop and a long needle to the starting cylinder loop upon loading which cannot be altered.

As illustrated in Figure appx-1.40, the module reads each cell upon loading by selecting an odd row from the canvas that corresponds to one dial course. If the cell number is odd, it assigns a zero to the cell; otherwise, it assigns a one. For subsequent even rows, it assigns a 1 to cells with an odd number and a 0 to cells with an even number. Thus, each pair of rows on the graph paper representing an actual fabric course receives opposite numbers in their cells. Once all cells have been numbered in accordance with the interlock configuration rule, the control proceeds to convert the values to short and long needle marks.

The control begins reading each cell again sequentially in order to convert the values to needle marks. If the cell value is 1, the long needle module is invoked to draw a long needle mark in the cell's center. If the value found is 0, the short needle module is invoked to draw a short needle mark on the cell. The values of the cells are then stored in a temporary memory location until they are sent to the database.

A plain interlock machine's needle setup is binary, with long and short needles placed one after the other in one bed and short and long needles placed one after the other on the opposite bed, so that long and short needles face each other in the opposite bed. It is possible that the needle sequence will need to be altered for design purposes. In that case, the designer can use the 'Gating tool' on the tool bar, which automatically converts a long needle to a short one and a short needle to a long one, as well as performing the opposite action on the other bed.

To keep gating simple, the module only allows alteration of gating on the first dial course or first row on the graph paper, and the action is automatically reflected on all subsequent rows. The needle marks change color in response to the mouse over action on the canvas. When the user moves the mouse over a needle, the default color of the needle where a loop would be drawn changes to red, informing the user of the current needle in use. When the mouse is moved to another needle, the previous needle is reset to its default color, indicating that it is no longer active. This is advantageous for the designer when he or she is putting a miss loop on the canvas.

3.3.4.7. The Notation Module

The notation module is in charge of converting specific user actions to loop notations and then drawing them on the canvas with the assistance of other sub modules. When the new design is invoked, it first assigns the value 0 to all cells in the canvas and stores the value in a temporary memory. The knit, tuck, and miss loop tools are located on the tool bar above the canvas. When one of them is invoked, the module calculates the user's mouse position on the canvas. If the mouse is on an odd row, the action is implied for dial loops; if the cursor is on an even row, the action is assigned for cylinder loops.

As illustrated in Figure appx-1.41, if the active tool is knit and the cursor is on an odd row, the clicked cell value is set to 4 and the dial knit loop module is invoked to draw the loop on the cell. If the clicked cell is in an even row, the cylinder knit loop module is invoked and a loop with cell value 1 is drawn. When a cell is clicked with a tuck loop, the value of the cell is changed to 5 if it is in an odd row and to 2 if it is in an even row and the respective loop is drawn. Similarly, the cell is assigned 6 if it is in an odd row indicating a dial miss loop and 3 if it is in an even row for drawing a cylinder miss loop. By clicking a cell with the 'Delete' tool, the cell value is reset to 0 and any existing notation on that loop is deleted. Again, if the user wishes to modify the loop of a non-empty cell, the module first invokes the delete module, which deletes the loop, and then draws a new loop with the new cell value in that cell.

While placing each loop, an intermediate module determines the yarn path that will connect the current loop to the previous one. This module compares each active loop to the needle type and determines which yarn should be connected to the current loop. Following detection of the source yarn, it assigns a color to the called loop module in order to draw the desired loop in that color. The user can change the color of a yarn by changing the interactive cell's fore color on the color palette. As soon as the user changes the color, the module identifies the respective yarn path and redraws all the loops of that yarn with the newly assigned color and refreshes the canvas. At the same time, it updates the color information of changed cells and stores them in temporary memory.

3.3.4.8. The Library Module

A complete interlock structure is a combination of the loop data from the cylinder and dial, the needle type data, the color data, and the course and wales data. At startup, the canvas is loaded with some predefined data and some user-defined data that are temporarily stored in memory. Each type of data in the preceding data set can be changed by drawing loops or by modifying the existing notation by changing the loops or colors. When a user calls the save action for a structure, this module first scans the entire temporary memory for changes. It then converts the most recent state of the memory value into predefined format and then sends to the appropriate database.

When the canvas is first loaded, as shown in Figure appx-1.42, this module reads the database and populates a drop-down combo that is located above the information panel on the right side of the canvas, with the names of all saved designs. This combo allows the user to access and reload previously saved structural designs. When a name is selected from the drop-down list, this module immediately loads related course and wales data, color data, loop data, and color information from the database into memory. Following that, the raw data is converted to a predefined format and routed to the appropriate modules. It first invokes the canvas generation module, which creates a canvas with the specified height and width and works as the container for graph paper, color palette and fabric information panel. The graph module is invoked, and the course and wales data are passed in to regenerate the graph.

The color palette module reads color data, converts it to component data, and reloads the user's saved color palette. To replicate the needle setup, the needle bed module is invoked. Finally, the structure module loads, it reads all of the loop information and redraws the loops on the screen with their assigned colors and addresses. After completing all of the tasks, the complete notation diagram appears on the screen, ready to be modified or validated. A saved structure can be completely deleted from the database after its loading onto the canvas. If a structure is deleted, the canvas refreshes to new design mode, the drop-down combo is refreshed to exclude the deleted structure’s name. Once deleted, a structure cannot be restored since the action is implemented both into the database and in the canvas.

3.3.4.9. The Color Palette Loading Module

This module is in charge of converting color codes retrieved from the database to a palette of colors. The color information for each course in the structure is stored in a text data type in the database. When this color text is retrieved, it is divided into the assigned number of courses and then each portion is further divided into RGB components to generate the color associated with the course.

As illustrated in Figure appx-1.43, the module reads the number of rows on the canvas and populates the color palette with that many cells. It then collects the number of characters assigned to define the color of a cell and begins reading a block containing that many characters from the color text. The block is then divided into three segments, each of which contains a three-digit number representing the red, green, and blue components. Following that, these three segments are passed through a library function that converts the digits to color. The color is then set as the foreground color for the color cell associated with the course. When the forecolor changes, the corresponding course's color changes as well. After completing one cycle, the module verifies that the current cell is the final one. If not, it moves on to the next cell and repeats the process with next block.

3.3.4.10. The Notation Regeneration Module

When a structure is saved to the database, the cell values representing a loop in the temporary memory are collected and sent to the database as text data types. When the structure is retrieved from the database again, this module collects that text data and converts it to appropriate loops and in combination with colors, the notation diagram is regenerated on the screen.

As illustrated in Figure appx-1.44, the module reads the structure text sequentially and associates each character with a cell on the graph paper. Simultaneously, it reads the needle value of the cell. If the needle value is 1 and the current cell is in an odd-numbered row, the module collects color information from the color palette's next cell. Otherwise, it provides the drawing pen with color from the corresponding cell on the color palette for the current row. The module then calls the cylinder knit loop module for loop value 1, the dial knit loop module for loop value 4, the cylinder tuck loop module for loop value 2, the dial tuck loop module for loop value 5, the cylinder miss loop module for loop value 3, and the dial miss loop module for loop value 6. The called module then uses the defined pen to draw the intended loop on the current cell, and the module repeats the process until it has completed all the cells on the graph paper.

3.3.4.11. The Width Detection Module

It is critical for any knitted structural design that the number of needles used in each course be consistent, and that all courses begin and end on the same needles. During the design phase, the designer may miss the rule, and the design becomes flawed as a result of the technician on the production floor's inability to interpret it. This module detects such inconsistencies and generates an error message if any are found.

As illustrated in Figure appx-1.45, the module reads the number of courses, number of wales, and notation data row by row upon loading. If the value of a row is greater than 0, the module trims the leading and trailing zeros and identifies the starting and ending cell addresses. If the variables StartingX and EndingX are not yet initialized, it initializes them and assigns the starting cell address to StartingX and the ending cell address to EndingX before proceeding to the next row. If the next row's starting cell address is less than StartingX, it updates StartingX; if the ending cell address is greater than EndingX, it updates EndingX. The process is repeated until the final row on the canvas is completed and the width of the structure is calculated from StartingX and EndingX.

3.3.4.12. The Structure Validation Module

This module searches for missing loops or missing courses in the current structure and displays an error message if one is discovered. As illustrated in Figure appx-1.46, the module loads two rows at a time and checks whether the combined value of the two rows is greater than 0. If the value is less than zero, the rows are empty, and the control moves on to the next pair of rows.

If the value for a pair of rows is greater than 0, the module reads the loop codes from StartingX to EndingX as defined in the previous module and adds them to a real course array. The codes are then divided into two sections, one for short needle course and another for long needle course, and checked to see if the value for short needle course is greater than 0. If the value is not greater than 0, the module returns an error indicating empty cells or absence of yarn in short needles. If the short needle course value is found to be greater than 0, it then checks each notation character in the course for the presence of a 0. Because 0 indicates the absence of loops, if found, it throws an error message informing the designer that the current position is missing a loop. If the short needle course does not contain any 0, the module switches to the long needle course and repeats the procedure. When both courses pass, it moves on to the next pair of rows and repeats the process until it reaches the end of the canvas and verifies all courses on it. If no such error is discovered, the structure is considered valid and suitable for structural repeat identification and further processing.

3.3.4.13. The Course Repeat Module

A repeat is the smallest unit of a structure's combination of loops in both the width and length directions, whose consecutive placement forms the fabric. Figure 3.12 illustrates a repeat in the Cellular Blister structure with a repeat size of 4×4, indicating that the repeat contains four courses and four wales. The identification of structural repeats is critical to the fabric development process because it provides precise information about the machine configuration and type of machine required. Additionally, it serves as a fundamental element for fabric simulation.

This module, as illustrated in Figure appx-1.47, determines the structure's course repeat. It begins by determining the total number of real courses in the structure defined in the previous module, and then identifies the structure's factors (n) and matching numbers (m) by dividing the total number of real courses by the factor. It then begins matching each block with the total notation for the actual course using a block of notation values as a seed equal to the number of courses (n).

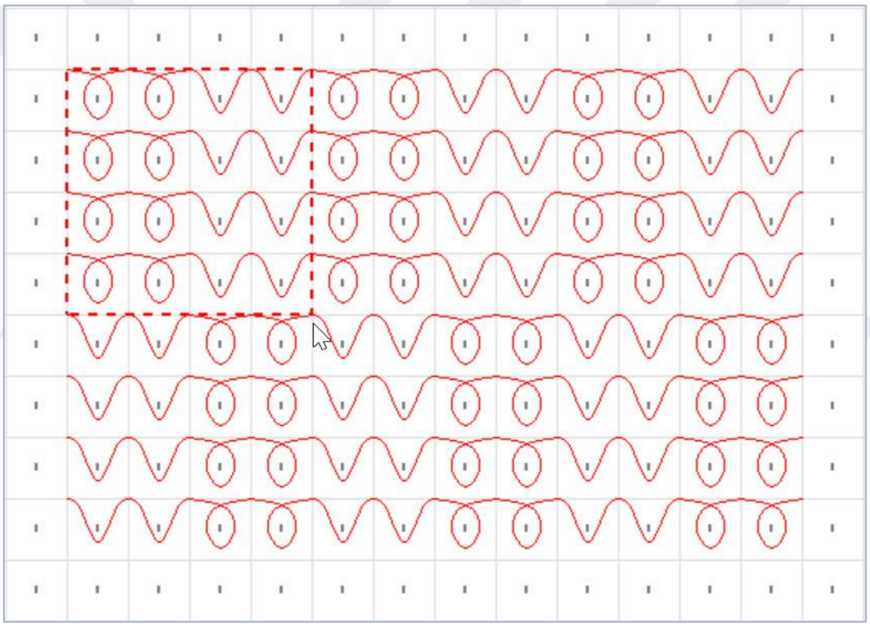


Figure 3.12. Repeat in a knitted structure

If the number of matches equals m, the block is considered to be the smallest repeat in the structure, and the routine exits. Otherwise, the routine performs the same checks on each factor until it reaches the final one. If the module is unable to find a repeat value from the factors, it decides the total structure is a repeat. Fabrics with a large repeat are occasionally impossible to manufacture due to machine constraints, as variation in wales increases the number of tracks in the cam box.

While a cylinder cam box can accommodate up to six tracks, a dial cam box cannot. As a result, the designer is constantly striving to create fabrics with a smaller repeat that fits within the machine's capacity.

3.3.4.14. The Wales Repeat Module

The wales repeat module uses the structural width and course repeat information determined by the previous modules to identify and define the wales repeat. As illustrated in Figure appx-1.48, this module at first extracts and stores cylinder and dial wales from the course repeat. It then counts the wales within the structure's actual width and calculates the number of possible factors (n) and matching possibilities (m) for each factor by dividing the total wales by the factor. It prepares the seed vale by extracting loop values from the wales that are equal to the factor and then begins matching the seed block by block within the total wales notation.

If the number of matches equals assumed m, it considers it to be the smallest possible repeat. If it is unable to identify a repeating pattern in the factors, it considers the total number of wales to be a repeating pattern.

The second routine is used to determine the repeating pattern in the needle arrangement. In contrast to single jersey and rib structures, where the needle arrangement varies according to the structure, in interlock, the needle type is defined prior to the structure's development. Though the needles are classified as short or long, they can be further classified according to the track to which they are assigned. Although the needle type is fixed prior to developing the structure, the subgrouping within that needle type can be rearranged after the structure is developed. Thus, the final repeat for interlock structure is not solely structural; rather, the final repeat is a combination of structure and needle type.

The module operates in the same manner as it did when determining the course repeat to identify the needle type repeat. If the number of wales repeats appears to be less than the number of needle repeats, the needle repeat is considered to be the structure's final repeat in wales. Otherwise, the structural wales repeat is regarded as the final repetition. This repeat selection can be perplexing for the technical person because the needle repeat is difficult to identify visually. Finally, by combining the course and wales repeat the actual structural repeat is defined.

3.3.4.15. The Machine Setup Module

The machine setup module determines the cam and needle configuration of the machine in order to produce designed fabric. As illustrated in Figure appx-1.49, this module takes each wales in the repeat and determines the required cam and needle type for each loop within the wales. If the dial needle type is short, it selects long for cylinder and short for dial; if the dial needle is long, it selects the opposite setup. It then populates the cam array with the appropriate cam type and proceeds to the next wales. When all the wales are complete, the cam list is sorted and converted to cam notation. Finally, it displays the cam and needle setup for the current structure on the screen, updating the information panel with the calculated cam notation.

4. RESULT AND DISCUSSION

4.1. Production Costing

To evaluate the costing module's accuracy, a fictitious organization with five departments was created. Two of the departments, common or administrative, and merchandising, were classified as service departments because they did not produce any physical product. They are responsible for providing logistical and administrative support to ensure the smooth operation of the other departments. The remaining three departments, namely the single jersey unit, the interlock unit, and the fleece unit, manufacture fabric of the single jersey, interlock, and fleece types and were considered to be production departments. Each department was virtually staffed and equipped with the necessary personnel and equipment. A dataset was created that contained the annual operating costs of the departments. Salary, establishment, rental, depreciation, utility bills, maintenance, bank interest, stationary items, hired transport, training, communication, advertisement, insurance, medical allowance, overtime bills, entertainment and others have been classified as cost heads. Each cost head was assigned an arbitrary value representing the annual cost. Table 4.1contains the dataset.

Pool Details | Salary details | Cost Summary

	Record ID	Employee Name	Designation	Yearly Salary (TL)	Last Modified	Comments
▸	1001-1001-10000	All	All	190000.00		Shows total of other cells
	1001-1001-10001	Jihan	Manager	50000.00		
	1001-1001-10002	Ruba	Technician	40000.00		
	1001-1001-10003	Talib	Officer	100000.00		

Figure 4.1. Sub-heads of salary in activity pool 'Common'

As illustrated in Figure 4.2, a similar dataset was fed into the costing module as input along with sub-heads in such a way that the summation of sub-heads matches the dataset value against a cost head. Figure 4.1 illustrates the sub-headings for the salary cost head in the 'Common' cost pool. The module also contains similar activity pools with exact cost heads as in the dataset.

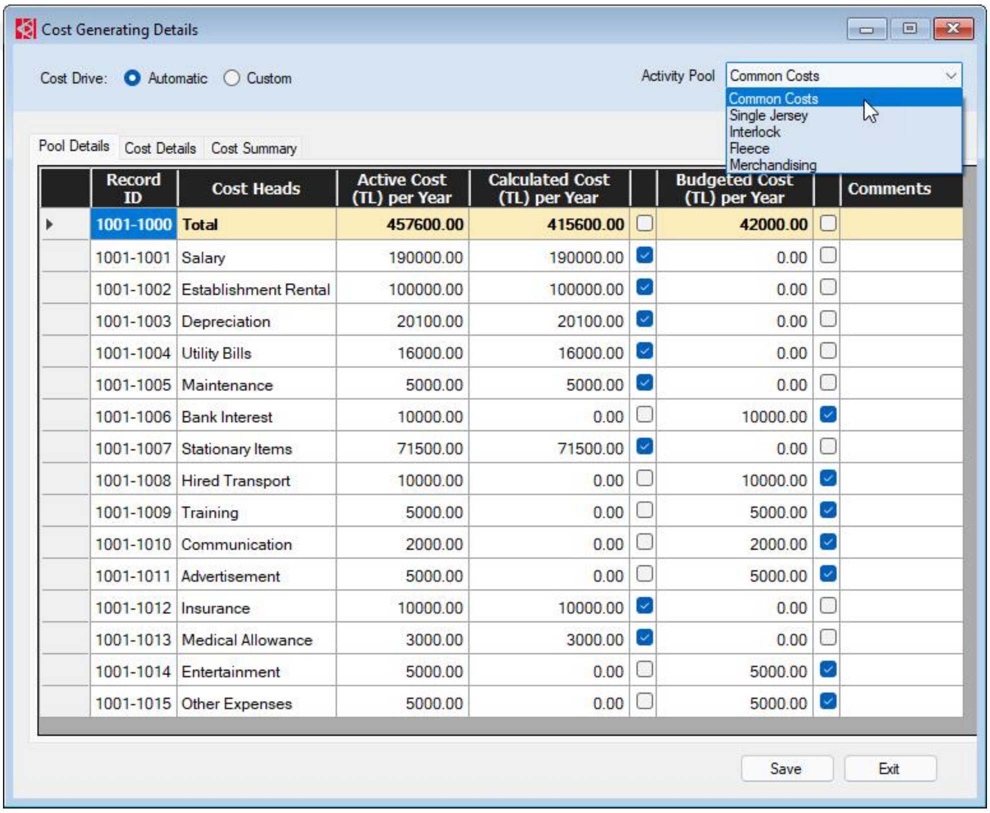
Table 4.1. Activity pool and cost heads

Cost Heads	Activity Pools				
	Common	Single Jersey	Interlock	Fleece	Merchandising
Salary	190,000.00	220,000.00	280,000.00	180,000.00	130,000.00
Establishment Rental	100,000.00	50,000.00	35,000.00	30,000.00	30,000.00
Depreciation	20,100.00	9,625.00	15,000.00	18,000.00	500.00
Utility Bills	16,000.00	30,000.00	35,000.00	15,000.00	500.00
Maintenance	5,000.00	24,000.00	30,000.00	25,000.00	500.00
Bank Interest	10,000.00	20,000.00	15,000.00	12,000.00	-
Stationary Items	71,500.00	5,000.00	5,000.00	2,000.00	500.00
Hired Transport	10,000.00	4,000.00	-	5,000.00	350.00
Training	5,000.00	1,000.00	8,000.00	2,000.00	150.00
Communication	2,000.00	5,000.00	15,000.00	1,500.00	400.00
Advertisement	5,000.00	-	-	-	-
Insurance	10,000.00	20,000.00	25,000.00	20,000.00	500.00
Medical Allowance	3,000.00	10,000.00	9,000.00	8,000.00	300.00
Over Time Bills	-	-	-	4,000.00	300.00
Entertainment	5,000.00	5,000.00	5,500.00	3,000.00	250.00
Other Expenses	5,000.00	5,000.00	12,000.00	4,000.00	500.00
Pool's Self Cost	**457,600.00**	**408,625.00**	**489,500.00**	**329,500.00**	**164,750.00**

[All the values are in TL]

The cost heads that do not have any sub-heads have been marked as 'Budgeted,' while the others are labeled as ‘Calculated’ in the module. When a cost head is labeled as budgeted, the module does not calculate the sub-heads associated with that cost head; instead, it considers the value specified under budgeted amount. In contrast, if a cost head is marked as calculated, it disregards the budgeted value and instead calculates the sub-heads and uses the calculated amount for further processing. If a cost head is neither calculated nor budgeted, its active cost becomes zero or is omitted from the calculation.

The total active cost of each pool was calculated manually. As can be seen, the figure is 457,600.00 TL for common, 408,625.00 TL for single jersey, 489,500.00 TL for interlock, 329,500.00 TL for fleece and 164,750.00 TL for merchandising. The software also calculated the values automatically and found the similar result.



Record ID	Cost Heads	Active Cost (TL) per Year	Calculated Cost (TL) per Year		Budgeted Cost (TL) per Year		Comments
1001-1000	Total	457600.00	415600.00	☐	42000.00	☐	
1001-1001	Salary	190000.00	190000.00	☑	0.00	☐	
1001-1002	Establishment Rental	100000.00	100000.00	☑	0.00	☐	
1001-1003	Depreciation	20100.00	20100.00	☑	0.00	☐	
1001-1004	Utility Bills	16000.00	16000.00	☑	0.00	☐	
1001-1005	Maintenance	5000.00	5000.00	☑	0.00	☐	
1001-1006	Bank Interest	10000.00	0.00	☐	10000.00	☑	
1001-1007	Stationary Items	71500.00	71500.00	☑	0.00	☐	
1001-1008	Hired Transport	10000.00	0.00	☐	10000.00	☑	
1001-1009	Training	5000.00	0.00	☐	5000.00	☑	
1001-1010	Communication	2000.00	0.00	☐	2000.00	☑	
1001-1011	Advertisement	5000.00	0.00	☐	5000.00	☑	
1001-1012	Insurance	10000.00	10000.00	☑	0.00	☐	
1001-1013	Medical Allowance	3000.00	3000.00	☑	0.00	☐	
1001-1014	Entertainment	5000.00	0.00	☐	5000.00	☑	
1001-1015	Other Expenses	5000.00	0.00	☐	5000.00	☑	

Figure 4.2. Trial dataset in the module

When the automatic cost driver is selected, the algorithm distributes the total service cost to the production department in proportion to their own costs. Manual calculation resulted in a total service cost of 622,350.00 TL, as shown in Table 4.2.

After allocating this sum proportionately to the production department's costs, the total active operating cost for a year of single jersey is 615,779.28 TL, interlock is 737,654.22 TL, and fleece is 496,541.50 TL.

Table 4.2. Cost distribution by automatic cost driver

Activity Pools	Self-Cost	Section Type	Type Total	Proportion	Final Pool Cost
Common Service	457,600.00	Service	622,350.00	0	
Merchandising	164,750.00	Service		0	
Single Jersey	408,625.00	Production	1,227,625.00	207,154.28	615,779.28
Interlock	489,500.00	Production		248,154.22	737,654.22
Fleece	329,500.00	Production		167,041.50	496,541.50
Total Annual Costs	**1,849,975.00**				**1,849,975.00**

[All the values are in TL]

The annual cost was then converted to an hourly operating cost. After adding 5% company profit and dividing by the number of production machines, as shown in Table 4.3, the operating cost per machine per hour in the single jersey unit was 18.45 TL, in the interlock unit was 22.10 TL, and in the fleece unit was 14.88 TL.

Table 4.3. Operating cost per machine per hour in a pool

Production Pools	Operating Cost / Year (TL)	Operating Cost / Hour (TL)	Company Profit	Machine in the Pool	Operating Cost (Machine / Hour) (TL)
Single Jersey	615,779.28	70.29	5.00%	4	18.45
Interlock	737,654.22	84.21	5.00%	4	22.10
Fleece	496,541.50	56.68	5.00%	4	14.88

It was assumed that a single jersey machine configured to a specific structure could produce 18 kg per hour, an interlock machine could produce 22 kg per hour, and a fleece machine could produce 25 kg per hour. Simultaneously, the single jersey machine generates 3.0 percent raw material waste, the interlock machine generates

4.0 percent, and the fleece machine generates 4.0 percent. By adding the raw material price and adjusting these figures, as shown in Table 4.4, the final cost of a kilogram of single jersey fabric comes to 62.83 TL, 53.00 TL for interlock fabric, and 52.60 TL for fleece fabric. The software, as shown in Figure 4.3, also calculated the cost of one kilogram of single jersey, interlock, and fleece fabric using similar parameters and found similar result as obtained in the manual calculation.

Table 4.4. Production cost per Kg

Pools Name	Operating Cost (Machine / Hr) (TL)	Production (Kg / Hr)	Operating Cost / Kg (TL)	Raw Material Cost / Kg (TL)	Wastage	Product Cost (TL per Kg)
Single Jersey	18.45	18.00	1.03	60.00	3.00%	62.83
Interlock	22.10	22.00	1.00	50.00	4.00%	53.00
Fleece	14.88	25.00	0.60	50.00	4.00%	52.60

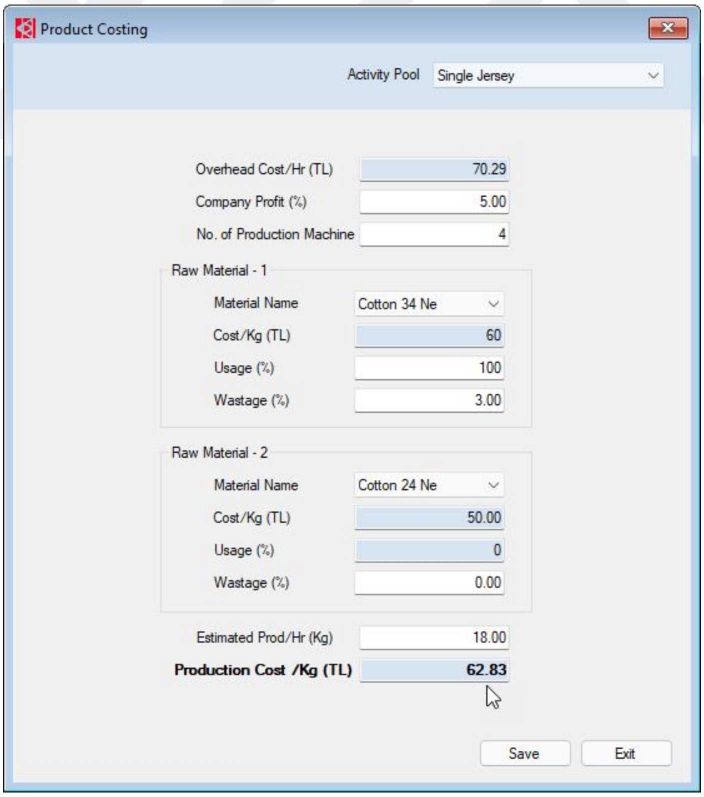


Figure 4.3. Production cost per Kg calculation

4.2. Fabric Characterization

This module provides quick count conversion and estimation of important fabric parameters that are related to yarn and machine variables, in accordance with the specifications. Several arbitrary count values were converted manually to check the accuracy of the module's count conversion capability. The results are shown in Table 4.5. The arbitrary value is displayed in the left column, and it has been converted to the other nine systems in the right column. A similar conversion was also performed in the software to ensure that the results of the software calculations were consistent with the results of the manual calculations. All of the results obtained by the software were consistent with those obtained by manual calculation.

Table 4.5. Verification of count conversion module

Converted from	Den	KTex	Tex	DTex	MTex	Nm	Ne	N_L	Nk	Nw
20 Denier		0.00	2.22	22.22	2,220	450	265.75	744.10	398.60	872
2 Kilo Tex	18,000		2,000	20,000	2,000,000	0.50	0.30	0.83	0.44	0.97
25 Tex	225	0.03		250.00	25,000	40	23.60	66.16	35.44	77.52
20 Deci Tex	18	0.00	2.00		2,000	500	295	827	443	969
25 Mili Tex	0.23	0.00	0.03	0.25		40,000	23,600	66,160	35,440	77,520
20 Metric	450	0.05	50	500	50,000		11.80	33.08	17.72	38.76
25 English Count	212.60	0.02	23.62	236	23,600	42.33		70	37.50	82
20 Linen	744.10	0.08	82.70	827	82,700	12.10	7.14		10.72	23.44
25 Worsted	318.88	0.04	35.44	354.40	35,440	28.23	16.68	46.68		54.70
20 Woolen	872	0.10	96.90	969	96,900	10.32	6.10	17.06	9.14	

Other necessary parameters have been organized into groups based on their functional interconnectedness. As shown in Figure 4.4, the user can select the fabric type and intended parameter. The right side of the screen automatically arranges related components to calculate a value when a parameter from the parameter group is selected as shown in Figure 4.5. When the target parameter in the parameter group is changed, the components on the right-hand side of the diagram change their arrangement. Each of the parameters was calculated manually in order to ensure that the software's calculations were correct. The results were identical, indicating that the equations in the background are performing perfectly.

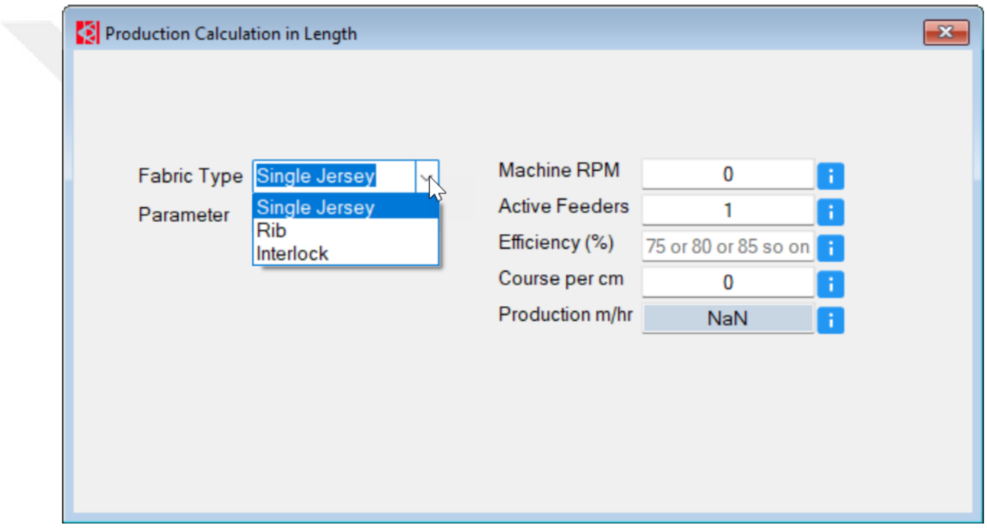


Figure 4.4. Parameters offered against base fabric type

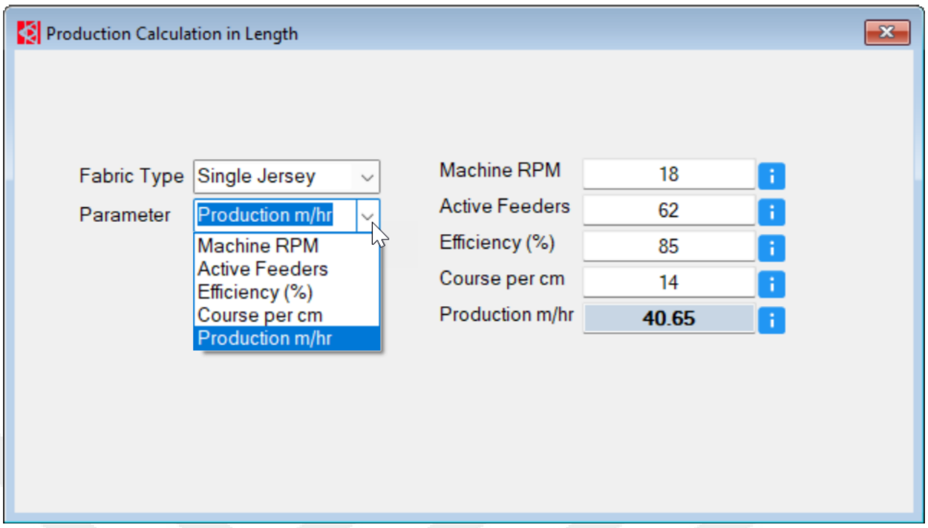


Figure 4.5. Parameters related to fabric length

Production calculation by weight encompasses machine rpm, active feeders, efficiency, machine diameter, machine gauge, stitch length and yarn count. Any of these parameters can be calculated when others are known as shown in Figure 4.6.

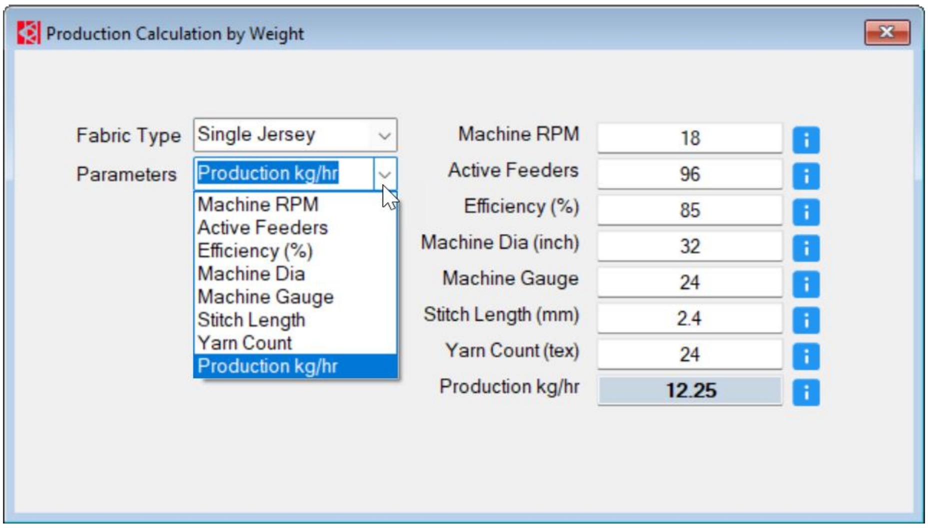


Figure 4.6. Parameters related to production calculation by weight

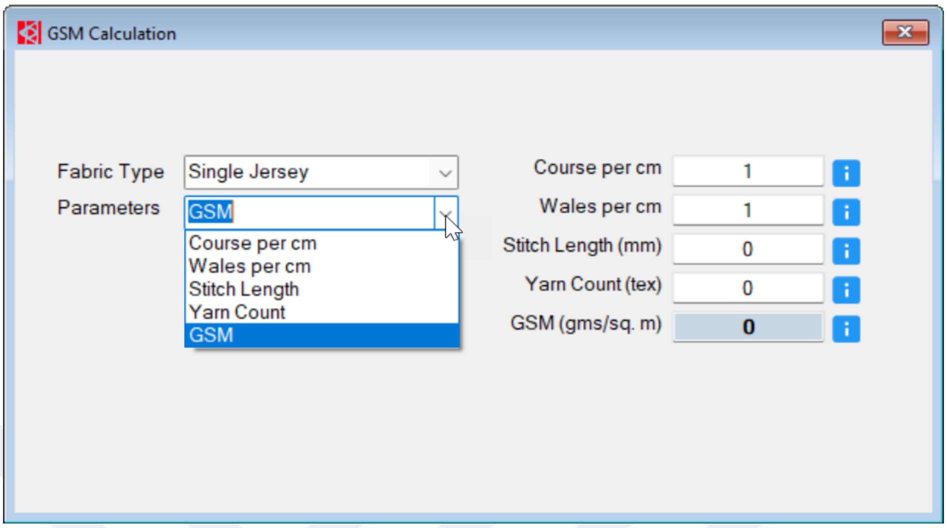


Figure 4.7. Parameters related to GSM calculation

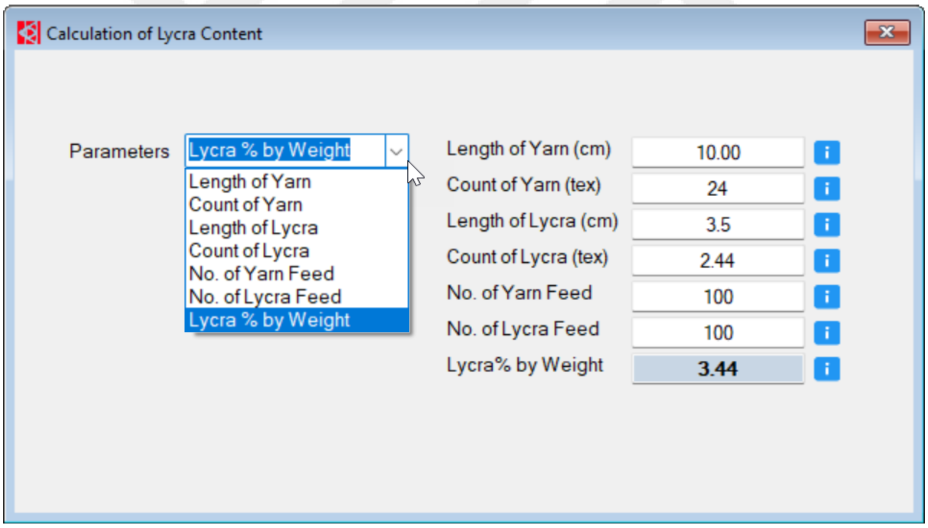


Figure 4.8. Calculation of elastane content in the fabric

Additionally, when the GSM calculation function is called, the module is loaded with the capability of calculating course per cm, wales per cm, stitch length, yarn count, and GSM. In many cases, the technician is required to insert a specific amount of elastane into the fabric. The fact that elastance or spandex is extremely delicate and can expand several times its original length, accurate calculation of its percentage appears difficult at times. As illustrated in Figure 4.8, the module accepts some input and accurately calculates the percentage of elastane present in the fabric under consideration.

A total of 75 parameters of yarn, fabric or machine can be estimated from this module. Among those parameters, the accuracy level of the prediction of the production rate in kg for single jersey, rib and interlock fabric as shown in Table appx-2.1, Table appx-2.2 and Table appx-2.3 are above 95%. While predicting the grams per square meter (GSM), as shown in Table appx-2.4, Table appx-2.5 and Table appx-2.6 respectively for single jersey, rib and interlock the accuracy level reached was above 80%, 94% and 81%. The variation in the prediction can be attributed to the relaxation time of the knit fabric. The GSM of knit fabric gets stable after a certain relaxation period after the production. If the given relaxation time is short, the measured GSM may come out low and it may increase up to a certain level after full relaxation. The prediction of elastane content in the fabric was found to outperform all other predictions. The module as shown in Table appx-2.7, achieved a similarity up to 99% with real time data in predicting the elastane content.

4.3. Fabric Design and Development

Fabric design and development involve designing a fabric from scratch or replicating a buyer swatch. If the designer cannot identify the actual structure of the buyer swatch, he or she must unwrap each yarn from the structure, draw each loop on the canvas as it unravels from the structure, validate the structure, identify the repeat, and then simulate the fabric to determine whether it looks similar to the given swatch. Each of the three modules, single jersey, rib, and interlock, has been developed with an abundance of functional options to aid the designer in his work. Along with development, all modules include machine setup modules that assist in determining the optimal machine configuration for manufacturing the structure on the machine. The modules have been thoroughly tested for bugs and found to be bug-free and functioning properly.

4.3.1. Development Environment

Each of the three modules as can be seen in Figure 4.9, Figure 4.10 and Figure 4.12 have been provided with necessary notation development tools, color tools and color palette, file handling tools, library access tools, structural information panels and machine setup information panels.

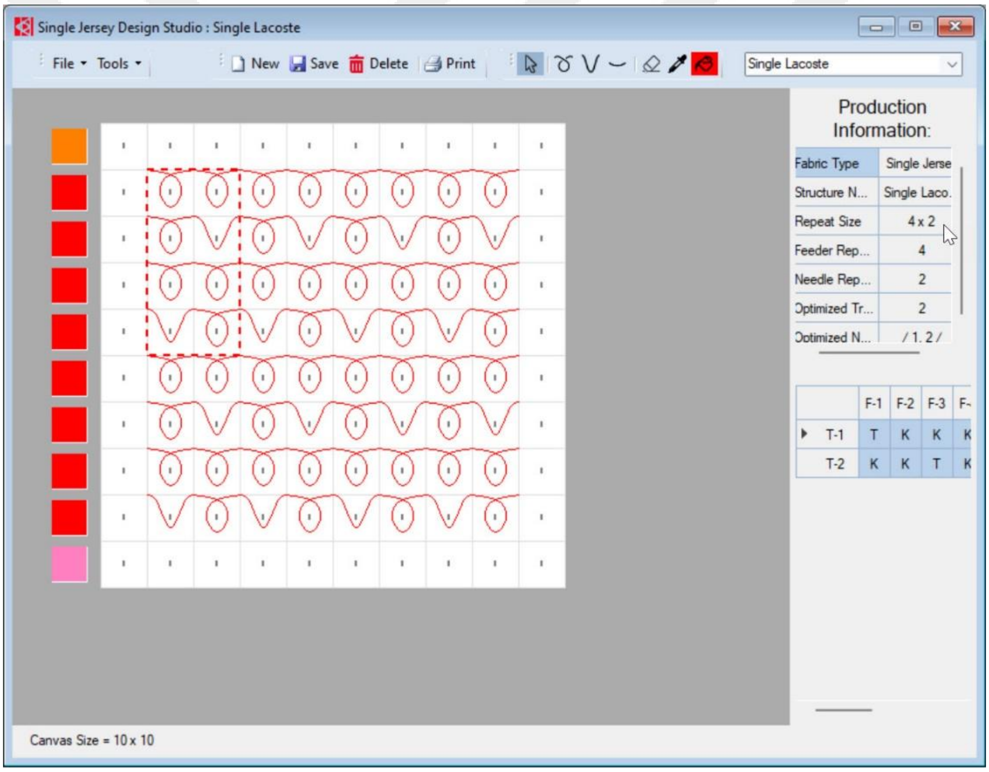


Figure 4.9. Single Lacoste structure development

The development process of the most widely used Single Lacoste structure in single jersey module (Figure 4.9), 3×2 Rib in rib module (Figure 4.10) and Half

Cardigan structure in interlock module (Figure 4.12) have been illustrated. The tools appeared to be working perfectly as intended.

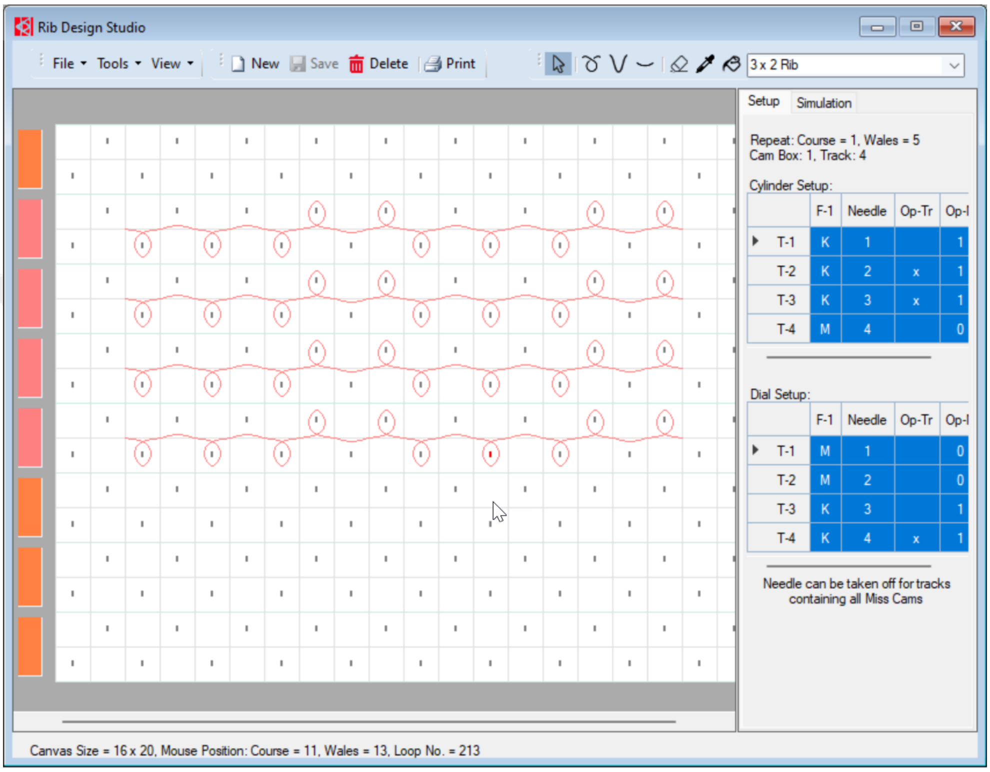


Figure 4.10. 3x2 Rib structure development

Although the tool bar contains only cylinder loop notation tools, each of the tools has dual functionality. When used on a single jersey module, the tools function exclusively as cylinder tools due to the single jersey machine's single bed. However, when tools the same tool is used on a double jersey module like rib or interlock, the dual functionality becomes available. The modules automatically determine the target course's nature; when a cylinder course is clicked, the tools provide cylinder loop functionality; when a dial course is clicked, the tools provide dial functionality. This has been implemented to keep the toolbar's number of tools to a minimum.

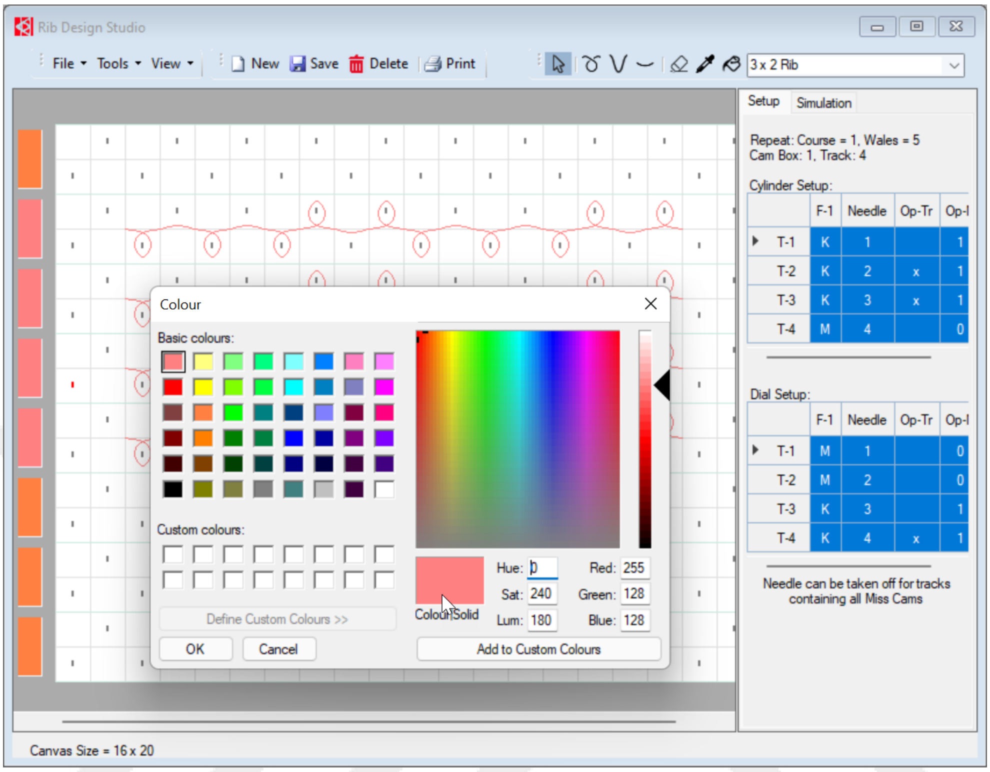


Figure 4.11. Color association in development modules

Each of the three modules now includes the entire color palette, allowing the designer to experiment with any color of his imagination while developing a new fabric idea. As illustrated in Figure 4.11, clicking on any color cell on the left side of the canvas invokes the built-in color palette of the windows. The user can choose from any of the prebuilt colors or alter the hue, saturation, and luminosity of a color or can develop a new color by changing the RGB values directly to match his appetite. When he confirms the new color's use, the forecolor of the clicked cell on the color palette changes, immediately changing the color of the associated course. When a user needs to ensure that the same color is used on multiple courses, the color picker and color filler tools come in handy. By clicking a cell with the color picker, the exact color is replicated, and the color picker fills the clicked cell with that color, eliminating confusion between colors that appear to be nearly identical.

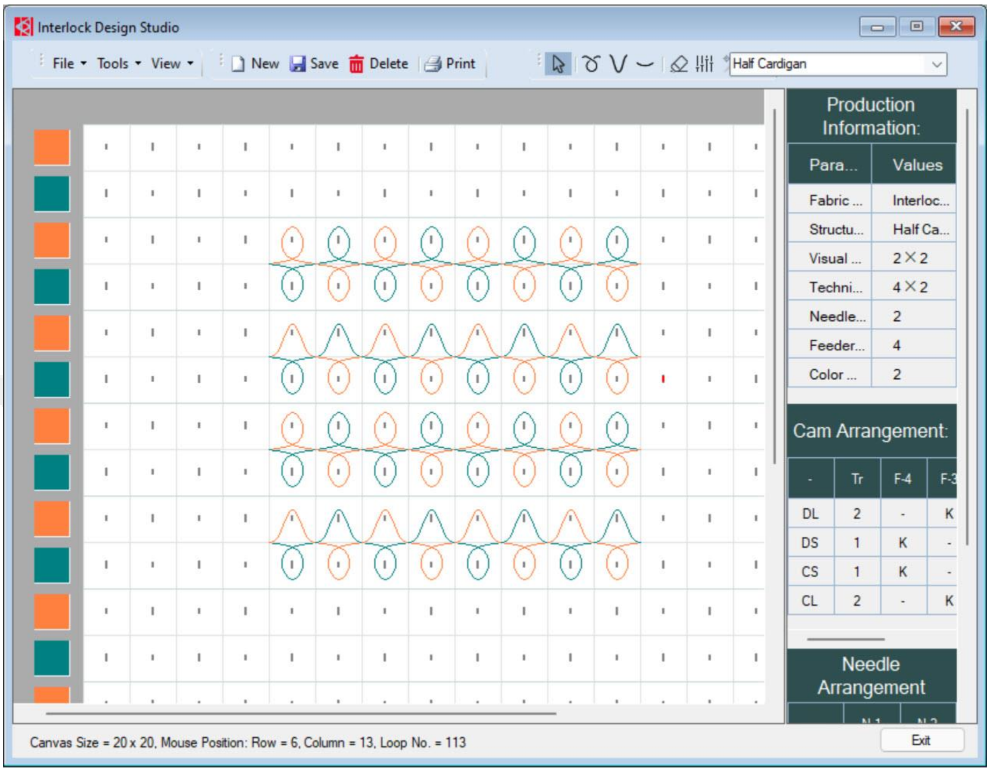


Figure 4.12. Half Cardigan structure development in Interlock module

The interlock module was carefully evaluated for each structure in the library to ensure that it correctly identified the yarn path and assigned the appropriate color without user intervention. Due to the fact that two yarns migrate from cylinder to dial and back again, automatically assigning an accurate color to a loop on dial or cylinder was critical, as an incorrect color assignment would indicate a false yarn, distorting structure validation and generating faulty machine configuration in cam setup and needle arrangement. Again, interlocking structures can be perplexing when visual assessment is used to determine the structural repeat. As a result, all structures were thoroughly screened for incorrect predication. The results were found to be flawless. As shown in Figure 4.12, the module is capable of correctly identifying the needle type and yarn path and automatically assigning the required yarn color.

4.3.2. Structural Validation

On each of the three modules, the action for determining the validity of structures was evaluated for any type of loop that was missing or followed an inconsistent path. Each module responded appropriately, accurately identifying any undesirable events occurring within the structures.

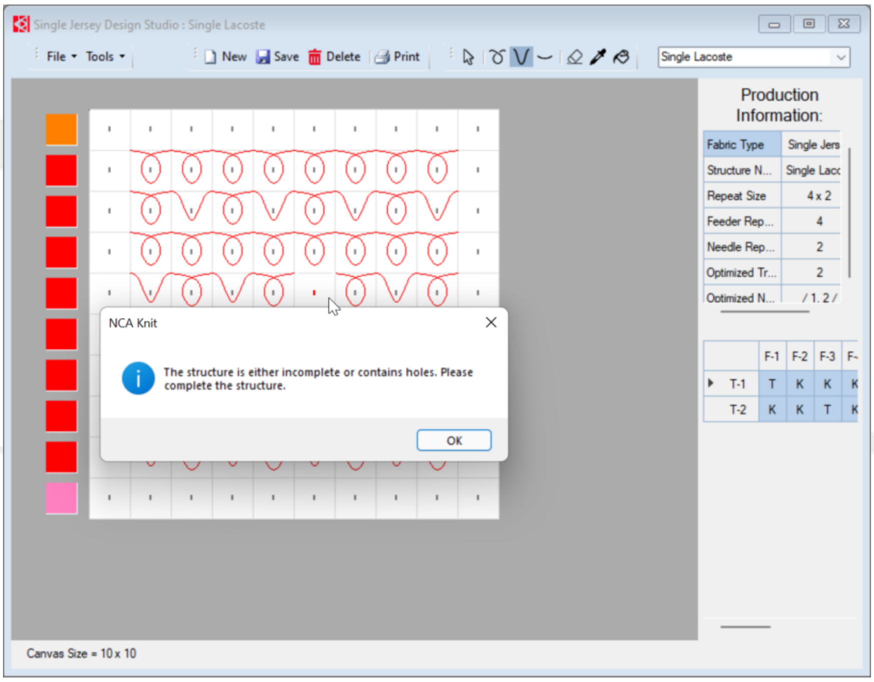


Figure 4.13. Structure validation in Single Jersey

As shown in Figure 4.13, the single jersey module correctly identified a missing loop in the Single Lacoste structure at position (4×5) and generated an error message informing the designer that the developed structure is either incomplete or contains holes. After generating the error message, the module terminated the active routine as expected, allowing the designer to make necessary corrections to the structure. Additionally, structures with an empty course or structures with an unequal number of needles were subjected to the action. The module was successful in identifying both an empty course and an unequal number of used needles, and generated a similar error message.

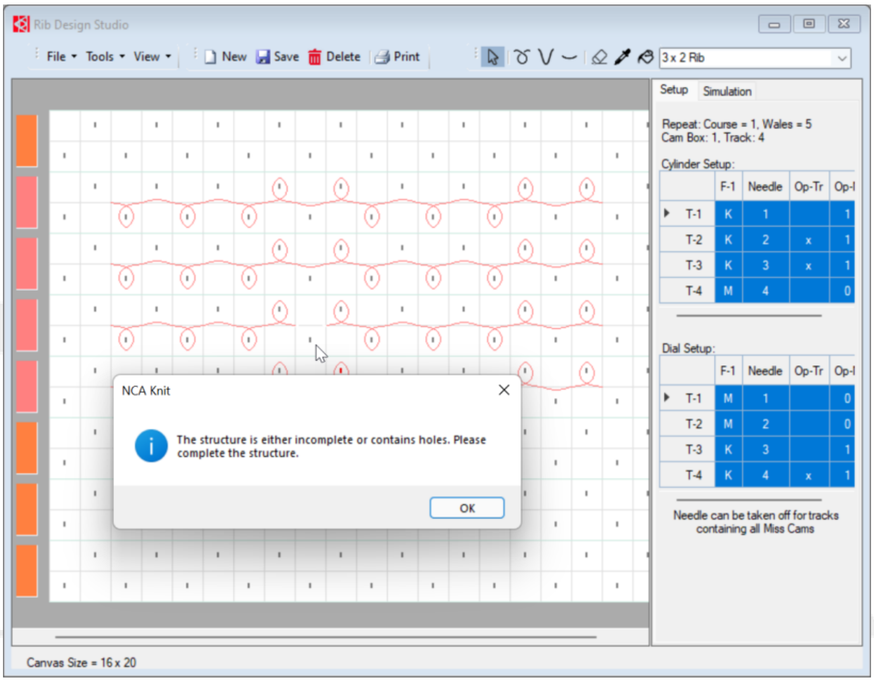


Figure 4.14. Structure validation in Rib module

As shown in Figure 4.14 and Figure 4.15, the validation routine was applied to a 3×2-rib structure in the Rib module and to a Half Cardigan structure in the interlock module in order to identify discontinuous yarn at locations (3×7) and (5×5) respectively. Both modules identified the discontinuation of yarn or the missing loops and generated the expected error message. The same routine was applied to a variety of rib and interlock structures in order to identify inconsistencies in the number of loops in courses within the structures. Because a valid structure requires that the number of loops in each course, regardless of knit, tuck, or miss, must be equal, and being otherwise is a fault, the validation routine was able to successfully identify and report such a discrepancy via an error message, halting further advancement of the active routine.

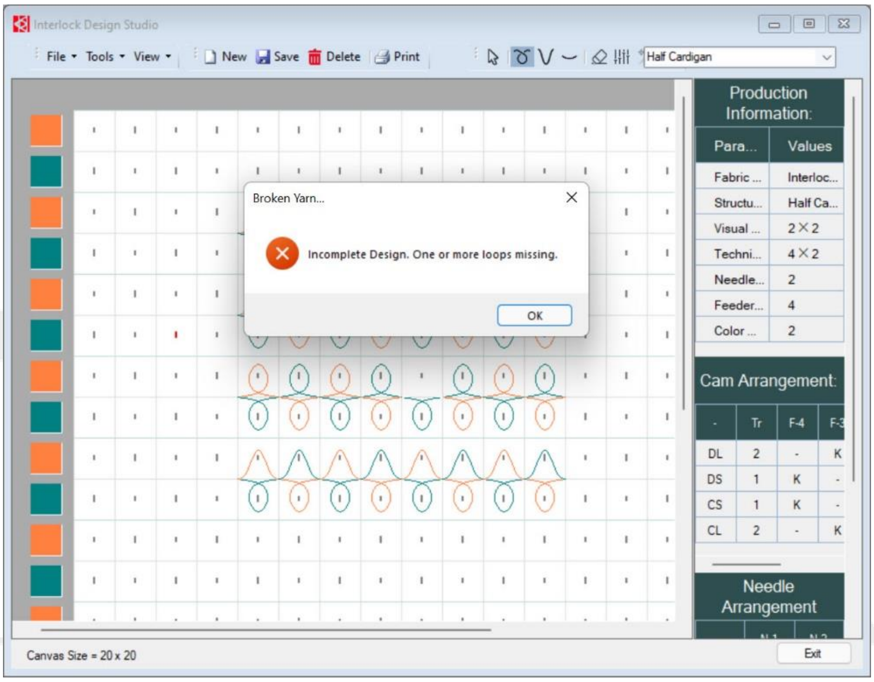


Figure 4.15. Structure validation in Interlock module

4.3.3. Structural Repeat Identification

The structural repeat of a knit fabric is critical because the cam arrangement, needle selection, and fabric simulation are all dependent on the fabric's structural repeat. As illustrated in Figure 4.9, the Single Lacoste structure has an 8x8 dimension, which means it contains eight courses, eight wales, and 64 loops. While developing a structure from a swatch provided by the buyer, even larger dimensions are occasionally required. After drawing the notation diagram, it is the designer's responsibility to optimize and determine the structure's repeating pattern. In this instance, the single jersey module automatically analyzed the structure and determined that the repeat is 4×2, indicating that the repeating pattern is composed of four courses and two wales, totaling eight loops. Similarly, in the Rib module, a

3×2-rib structure with 40 loops on 4×10 dimensions was developed, but the module, as illustrated in Figure 4.10, identified the repeating pattern as 1×5 with only five loops. In the same way, as illustrated in Figure 4.12 for the Half Cardigan structure, the interlock module identified the repeat as technically 4×2, visually 2×2 against the technical 8×8 dimension. The routine was also evaluated for a variety of other single jersey, rib, and interlock derivatives, and the results consistently matched manual assessment.

4.3.4. Machine Setup

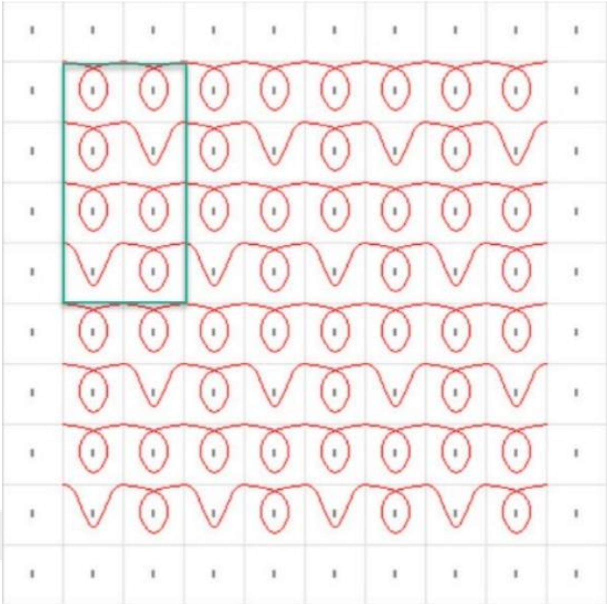
The term "machine setup" refers to the cam configuration and needle arrangement that should be used for a particular structure. The software module evaluated several single jersey structures in order to determine the cam setup and needle arrangement. Each trial result perfectly matched with the manual calculation.

As shown in Table 4.6, the manually calculated cam setup for Single Lacoste structure is four feeders with minimum two tracks. The first track is composed of one tuck and three knit cams whereas the second track is composed of two knit, one tuck and then one knit cam again. The needle arrangement is /1,2/ for the optimized cam setup. The single jersey module also found the similar optimized result for the same structure.

As for rib, the module result is shown for 3×2 structure in Table 4.7. The manual calculation shows that, in optimized setup, the machine requires only one feeder as repeat having a single track with knit cam both in cylinder and dial. The needle arrangement for cylinder and dial came out to be /1,1,1,0 × 0,0,1,1/. The exact result is suggested by the rib module also. Additionally, the rib module suggested the liner cam setup and needle arrangement should the technician prefer it to the optimized one.

Table 4.6. Calculation of cam setup and needle arrangement in Single Jersey

Single Jersey Module

<table>
<tr><td>Given Structure</td><td></td></tr>
<tr><td>Cam Setup and Needle Arrangement</td><td>
<table>
<tr><td rowspan="3">Manually Calculated</td><td>Tr</td><td>F1</td><td>F2</td><td>F3</td><td>F4</td><td>N</td></tr>
<tr><td>1</td><td>T</td><td>K</td><td>K</td><td>K</td><td>1</td></tr>
<tr><td>2</td><td>K</td><td>K</td><td>T</td><td>K</td><td>2</td></tr>
</table>
<table>
<tr><td rowspan="3">Software Calculated</td><td>Tr</td><td>F1</td><td>F2</td><td>F3</td><td>F4</td><td>N</td></tr>
<tr><td>1</td><td>T</td><td>K</td><td>K</td><td>K</td><td>1</td></tr>
<tr><td>2</td><td>K</td><td>K</td><td>T</td><td>K</td><td>2</td></tr>
</table>
</td></tr>
</table>

[Tr = Cam track, F = Feeder, K = Knit cam, T = Tuck cam, N = Needle number]

The interlock module was also assessed against many structural variations for detecting the machine setup. The result against Half Cardigan structure has been shown in Table 4.8. Manual calculation shows that, the structure requires four feeders repeat each feeder having two tracks in dial and two tracks in cylinder. In the dial long track, the cam sequence is miss, knit, miss and tuck cam whereas in the short track, the cam sequence is knit, miss, tuck and miss. In the cylinder, for short track, the cam sequence is knit, miss, knit and miss but for long track, it is miss, knit, miss and knit. The needle arrangement for cylinder and dial are /2,1 × 1,2/. The similar result was suggested by the interlock module.

Table 4.7. Calculation of cam setup and needle arrangement in Rib

<table>
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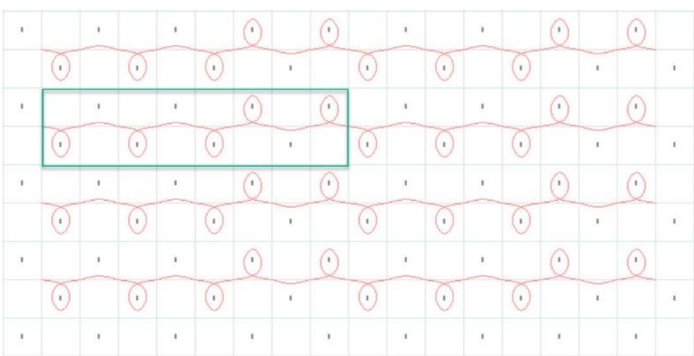
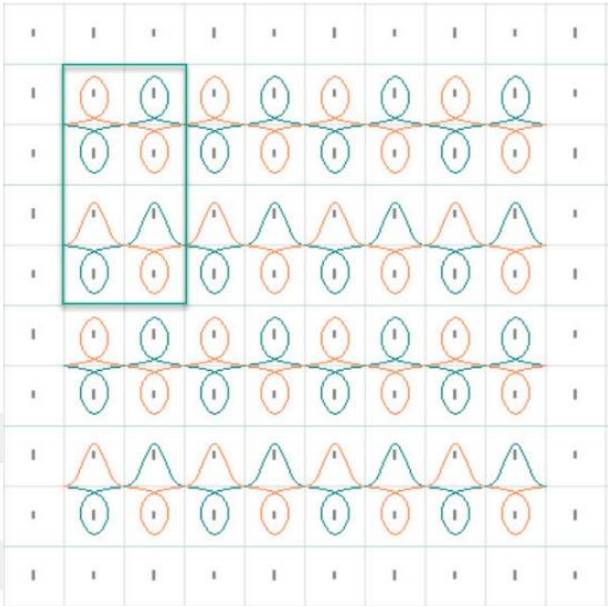
<tr><td>Given Structure</td><td></td></tr>
<tr><td>Cam Setup and Needle Arrangement</td><td>
<table>
<tr><td rowspan="3">Manually Calculated</td><td></td><td>Tr</td><td>F1</td><td>N1</td><td>N2</td><td>N3</td><td>N4</td><td>N5</td></tr>
<tr><td>D</td><td>1</td><td>K</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>C</td><td>1</td><td>K</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td></tr>
</table>
<table>
<tr><td rowspan="3">Software Calculated</td><td></td><td>Tr</td><td>F1</td><td>N1</td><td>N2</td><td>N3</td><td>N4</td><td>N5</td></tr>
<tr><td>D</td><td>1</td><td>K</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>C</td><td>1</td><td>K</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td></tr>
</table>
</td></tr>
</table>

[D = Dial, C = Cylinder, Tr = Cam track, F = Feeder, K = Knit cam, N = Needle number]

Table 4.8. Calculation of cam setup and needle arrangement in Interlock

<table>
<tr><th colspan="2">Interlock Module</th></tr>
<tr><td>Given Structure</td><td></td></tr>
<tr><td>Cam Setup and Needle Arrangement</td><td>
<table>
<tr><td rowspan="5">Manually Calculated</td><td></td><td>Tr</td><td>F4</td><td>F3</td><td>F2</td><td>F1</td><td>N</td></tr>
<tr><td>DL</td><td>2</td><td>M</td><td>K</td><td>M</td><td>T</td><td>2</td></tr>
<tr><td>DS</td><td>1</td><td>K</td><td>M</td><td>T</td><td>M</td><td>1</td></tr>
<tr><td>CS</td><td>1</td><td>K</td><td>M</td><td>K</td><td>M</td><td>1</td></tr>
<tr><td>CL</td><td>2</td><td>M</td><td>K</td><td>M</td><td>K</td><td>2</td></tr>
</table>
<table>
<tr><td rowspan="5">Software Calculated</td><td></td><td>Tr</td><td>F4</td><td>F3</td><td>F2</td><td>F1</td><td>N</td></tr>
<tr><td>DL</td><td>2</td><td>M</td><td>K</td><td>M</td><td>T</td><td>2</td></tr>
<tr><td>DS</td><td>1</td><td>K</td><td>M</td><td>T</td><td>M</td><td>1</td></tr>
<tr><td>CS</td><td>1</td><td>K</td><td>M</td><td>K</td><td>M</td><td>1</td></tr>
<tr><td>CL</td><td>2</td><td>M</td><td>K</td><td>M</td><td>K</td><td>2</td></tr>
</table>
</td></tr>
</table>

[Tr = Cam track, F = Feeder, N = Needle number, DL = Dial long track, DS = Dial short track, CS = Cylinder Short track, CL = Cylinder long track, K = Knit cam, T = Tuck cam, M = Miss cam]

4.3.5. Visual Simulation

The visual simulation enables the user to visualize the finished fabric before it is manufactured. Thus, the designer can visualize his imagination on the screen without consuming any physical material or wasting any sample production time. He is capable of creating hundreds of color variations in the fabric and determining which structural and color combination would be more appealing to the customer. If the designer works with a given buyer sample, he can simulate the structure before moving forward with actual production to ensure that the structure he identified matches the structure the buyer desired. In a competitive market, it is common for producers to communicate with electronic sample with the buyer that is merely a simulated view of the actual fabric. The simulation module enables the user to generate as many electronic samples as desired, each with a different yarn property or machine parameter.

As illustrated in Figure 4.16, the well-known Single Lacoste structure has been simulated in red color (255,0,0) against a machine with a npi of 24, a yarn count of 24Ne, and a stitch length of 2.4mm. The simulated view is as lifelike as the actual fabric produced by the machine. In Figure 4.17, the same structure has been simulated again using two color combinations while maintaining all other parameters. The result demonstrates a dramatic change in appearance simply by changing the color combination, indicating that fabric appearance is not solely structural in nature, but can be subdued through color combination. It is expected that fabric designers will benefit from this tool because they will be able to visualize and assess each of their design concepts. Figure 4.18 illustrates the intermeshing of the yarn path and loop at a 400 percent magnification of the original simulated view. Figure 4.19 shows an additional collection of color variation of the same Single Lacoste structure using the same yarn and machine parameters.

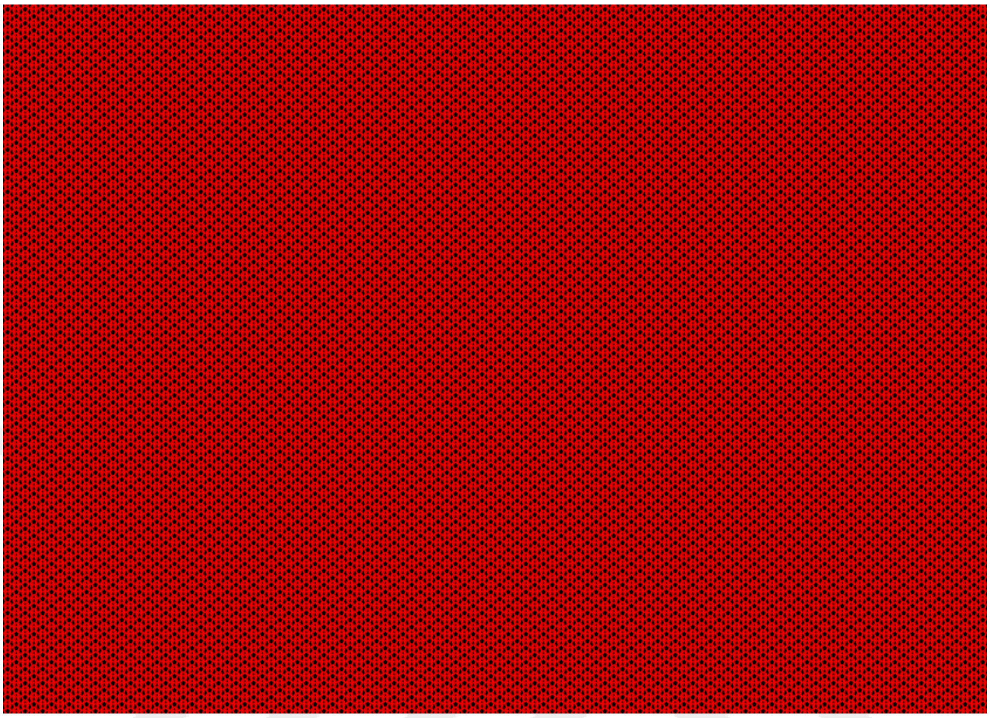


Figure 4.16. Single Lacoste simulated with 24 gauge, 24Ne and 2.4 mm SL

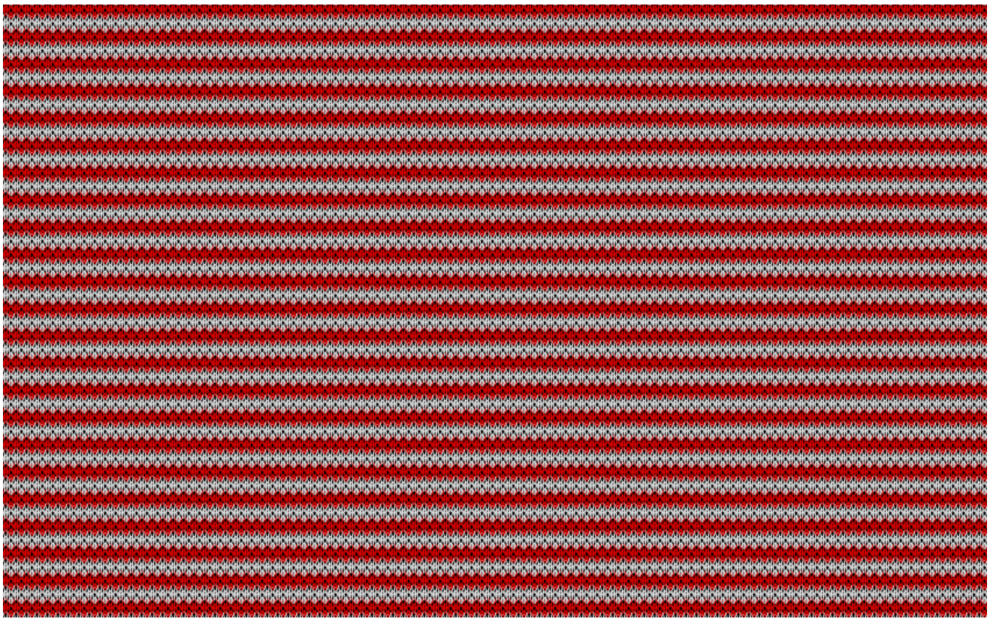


Figure 4.17. Single Lacoste structure simulated with two colors

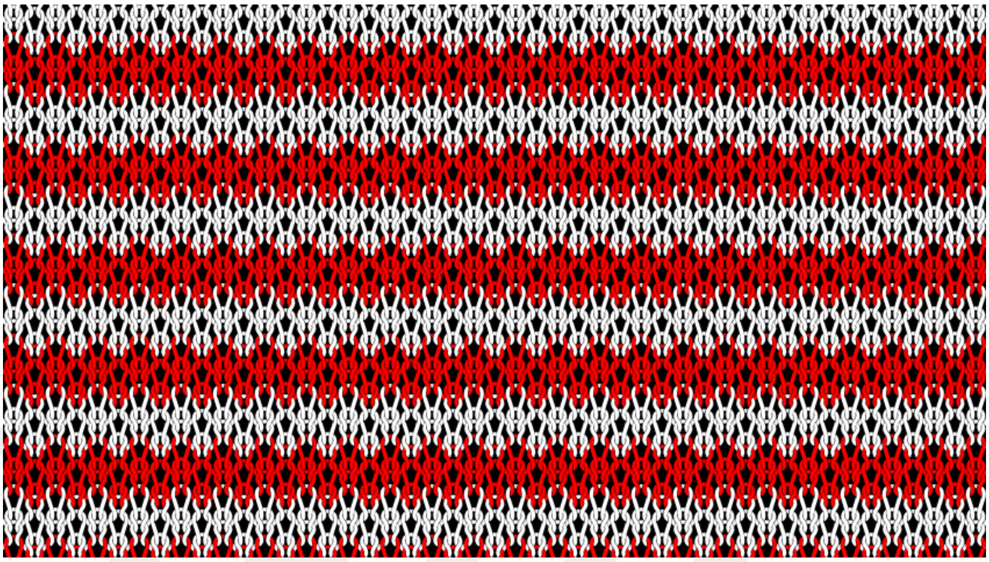


Figure 4.18. Single Lacoste structure enlarged to 400% zoom.

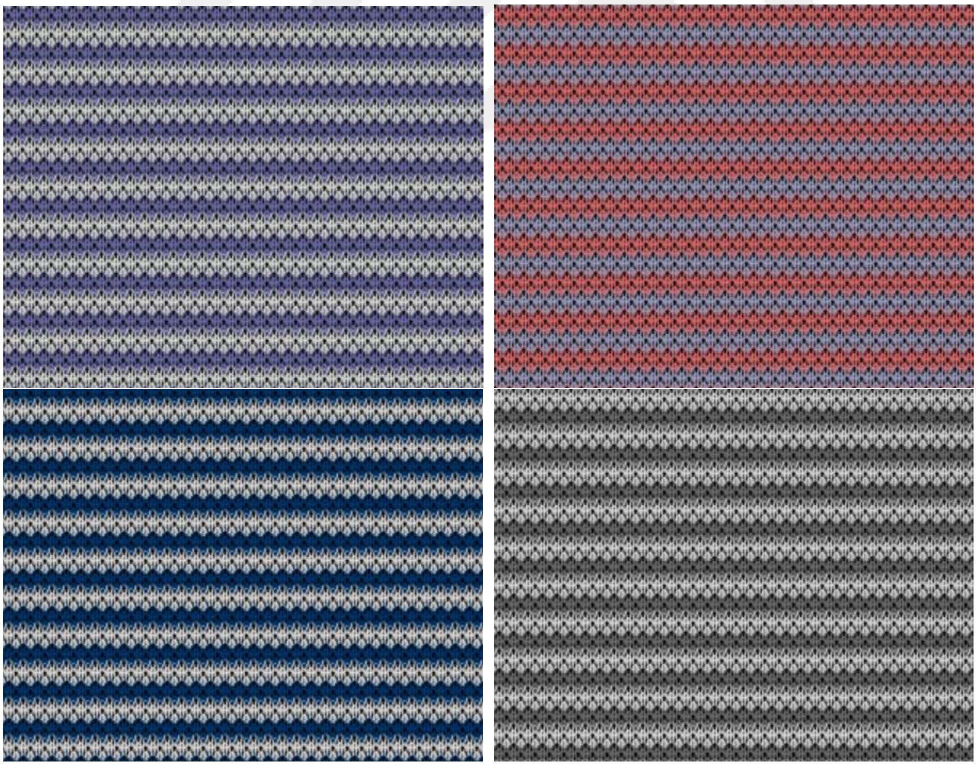


Figure 4.19. Single Lacoste structure simulated with color variation

Since single jersey is the mostly used weft knit fabric for fine-gauge, throughout the development work, most attention was paid to single jersey module to make it perfect. The geometric models working behind were updated several times to achieve mathematical accuracy and as close similarity as possible with the actual fabric. The simulation of the single jersey module is dynamic meaning that, the view responds with any change of yarn or machine parameters. In contrast the rib module is static, it was supposed to update the rib module when single jersey module is finalized. Due to lack of enough time, at this point, the rib module will not respond with machine parameters, but it simulates the given structure with predefined parameters. A simulated view of the 3×2 rib fabric has been shown in Figure 4.20. A more responsiveness and the simulation of interlock fabric can be added using the same updated geometric model used for single jersey module.

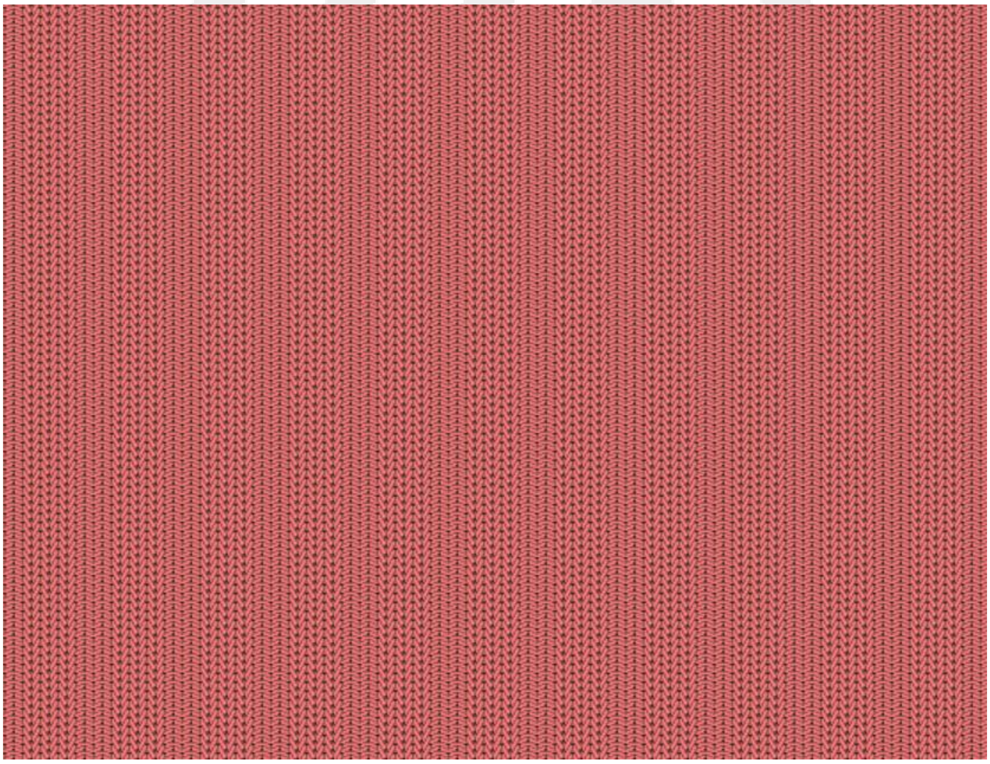


Figure 4.20. 3x2 Rib structure simulated in single color

As to evaluate the performance of the development and simulation module, a number of real time fabric samples were collected from knitting factory called IslandDenim in Adana, Turkiye. Picture of the collected samples were captured using a 16.2-megapixel camera with carl zeis lens. The fabrics were then simulated with similar construction and yarn parameters. The development module was successful to accurately identify the similar cam and needle arrangement for the structures as used for machine setup in the factory. The simulated face and back view of the sample fabrics as shown in Figure appx-3.1to Figure appx-3.9 were quite acceptable. A 400% magnified simulated view of face and back side of fabrics have also been shown in the said figures in appendix-3.

5. CONCLUSION AND RECOMMENDATIONS

The technological world is progressing at a breakneck pace, and keeping up is essential for survival in this environment. As a result, accepting the way the world behaves allows one to stay one step ahead of the game. The situation is the same in the manufacturing industry as it is elsewhere. The use of computer technology in the manufacturing plant to the greatest extent possible is a requirement. The goal of this research work has been to provide the knit manufacturing plant with the tools it needs to get to that playground.

The costing module has the capability of calculating the cost of production with pinpoint accuracy in mind. If this module is properly maintained and contains the necessary data, the managerial personnel can obtain accurate costing information from it before entering into a negotiation with a buyer or before launching a new design into the market. Thus, the organization can eliminate the need for average costing and compensation programs. A large number of widely accepted formulas are used in the characterization module to calculate and estimate fabric parameters based on yarn and machine parameters. This module will assist in reducing the number of trials required for a specific product match while at the same time reducing the number of errors in raw material selection.

To assist fabric technologists in developing a structure and saving it for future reference, the fabric development module provides them with all of the tools they need. Instead of using a pencil and eraser to sketch out a structure on graph paper, the automated method will be used instead. At the same time, thanks to its robust color combination capability, the designer will be able to create variants with virtually limitless color mixing possibilities and preview the appearance performance of the fabric before it is manufactured. As a result, not only will the development time be significantly reduced, but the costs of sample development and the boundaries of imagination will also be reduced.

Throughout the development process, the algorithms, which serve as the foundation of coding, have received the greatest amount of attention. In order for the background engine to function correctly, less attention has been paid to interface design. Further development will allow for the creation of a user-friendly interface while maintaining the functionality of the background engine.

Interlock holds a comparatively smaller portion in the market share; therefore, interlock module was developed in the last sequence. This module works perfectly up to machine setup and needle setout but simulation has been included in the module. It is due to the difficulty in developing a mathematically sound yarn distribution model for a given situation. Despite the fact that this model was finally developed, it required a significant amount of time in its validation, modification, coding, and final validation once more. Using this module, the single jersey simulation is flawlessly implemented. Consequently, it is anticipated that the same model will be applicable in the interlock as well.

The toolbar of the parent form contains a number of additional menu options. These have been included with the intention of converting the system to be able to handle all aspects of the work in a knit factory as well. The system can be extended to handle all types of managerial tasks such as manpower management, production follow-up tasks, buyer management, and total material sourcing, among others. Those aspects have been left out of the scope of this research work, but they can be considered if they can provide additional assistance to the knit sector.

Elasticity is an inherited property from the structure of the weft knit fabrics. The model still does not cover the elastic property. For more lively simulation, elastic property can be included in the model. There are numerous finishing parameters which come into handy for different types of finishing processes for knit fabrics. Further development can include estimation capability for those parameters also.

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APPENDICES

APPENDIX-1: Algorithms

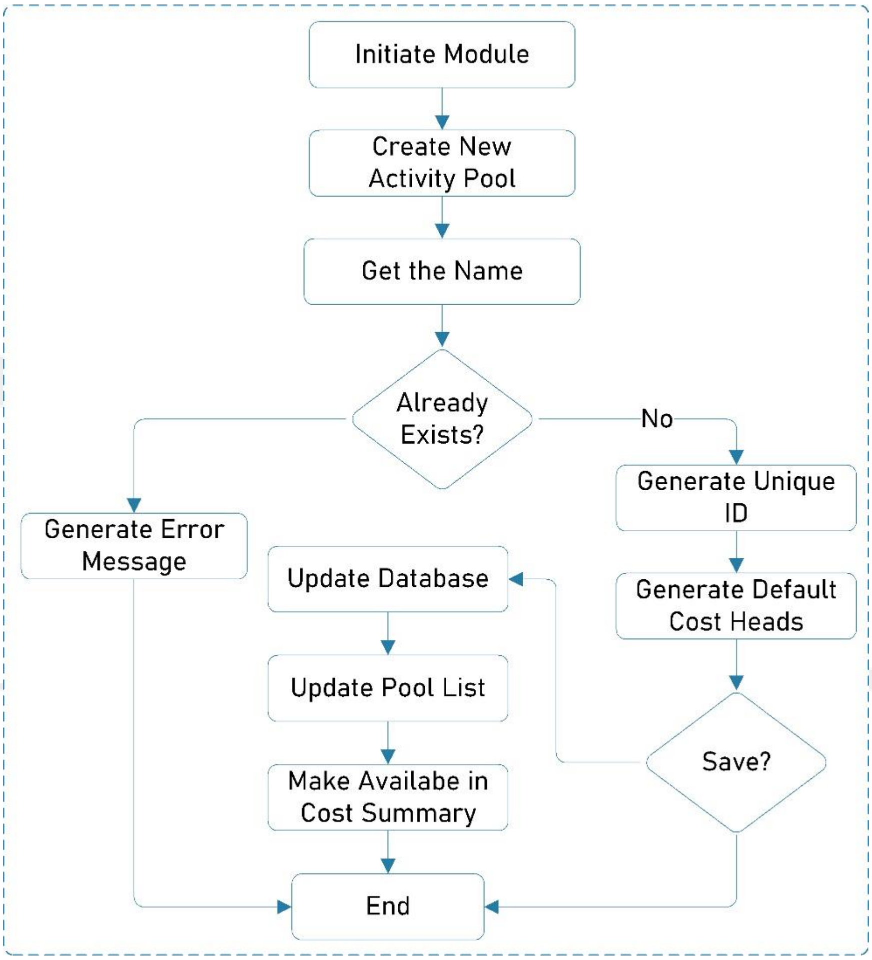


Figure appx-1.1. Registration of new Activity Pool

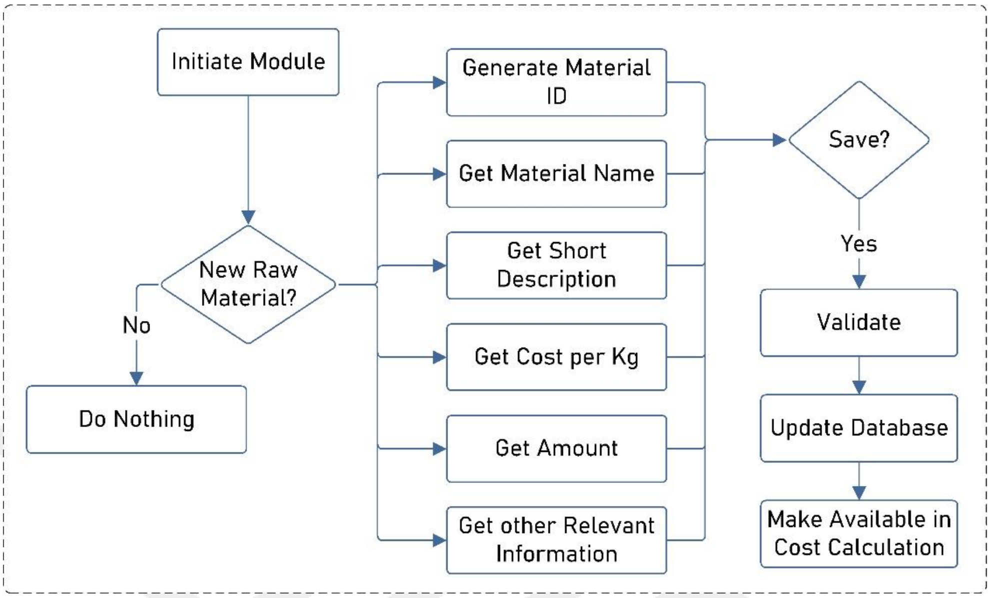


Figure appx-1.2. Registration of new raw material

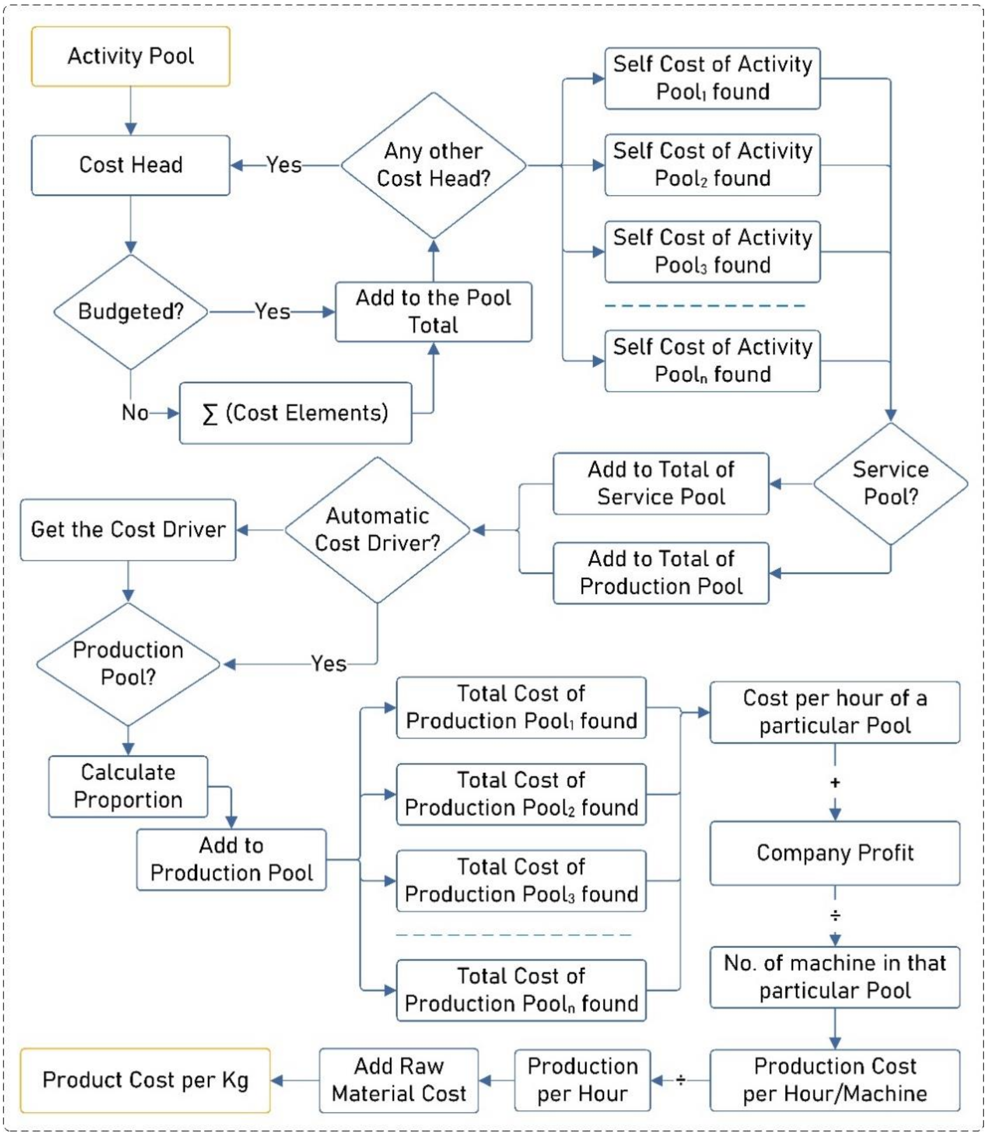


Figure appx-1.3. Pool coordination and calculation of product cost

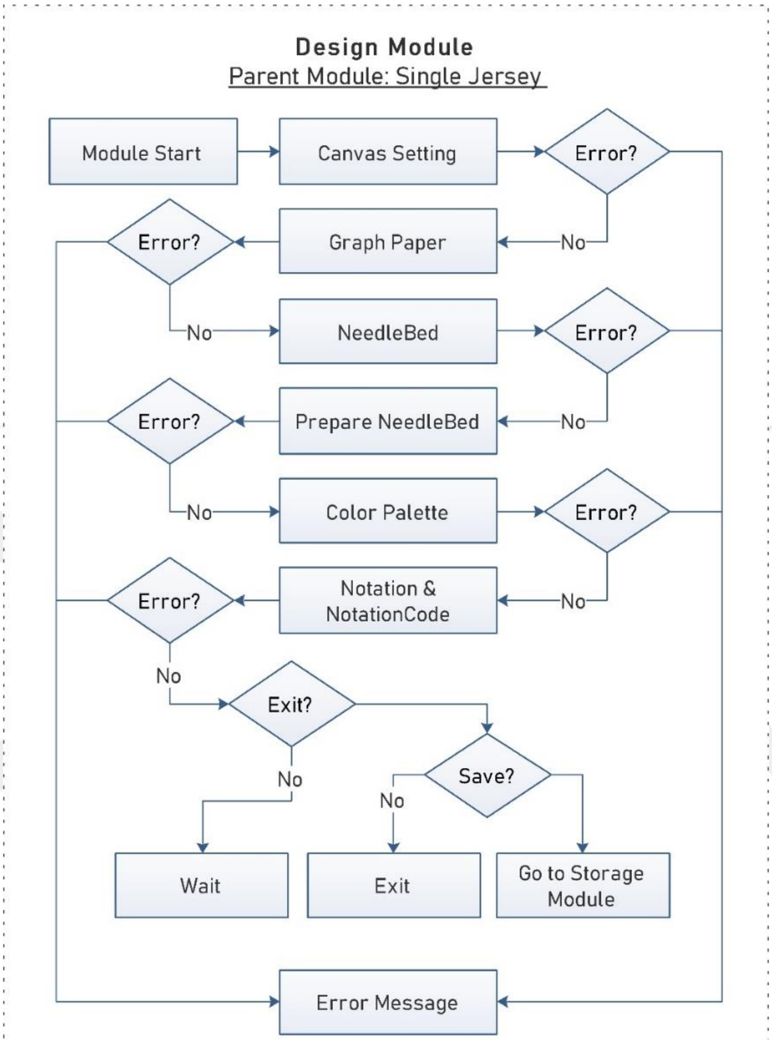


Figure appx-1.4. Algorithm for design module in single jersey

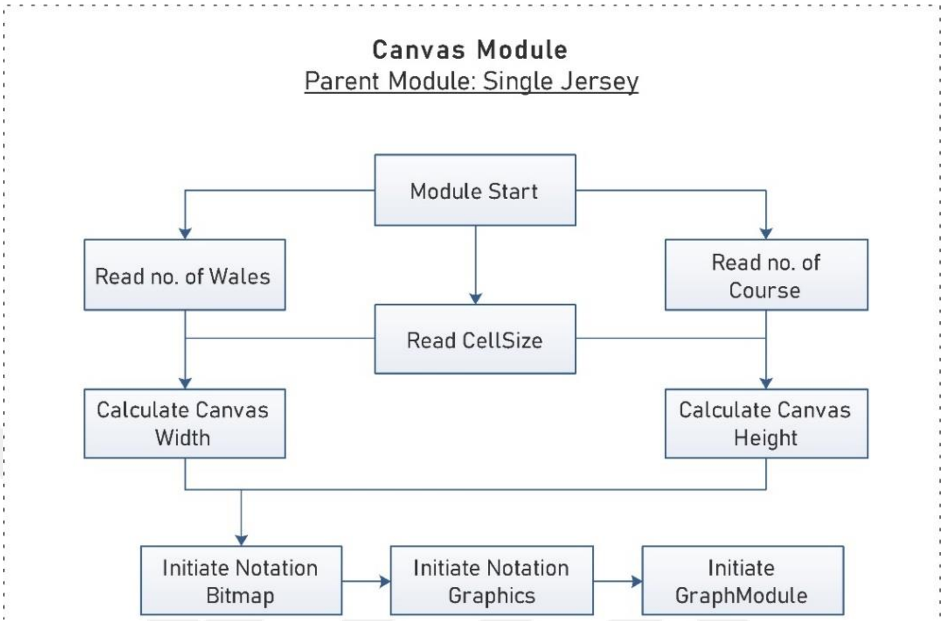


Figure appx-1.5. Algorithm for canvas module in single jersey

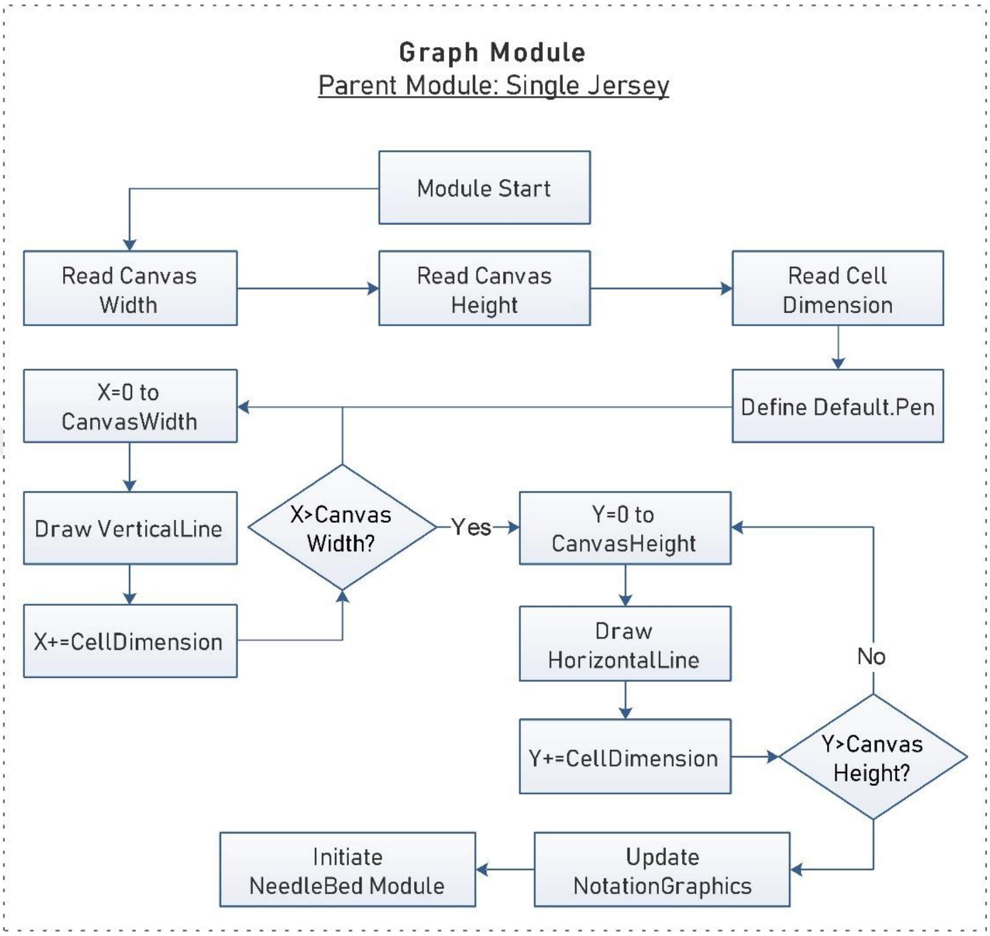


Figure appx-1.6. Algorithm for graph paper in single jersey

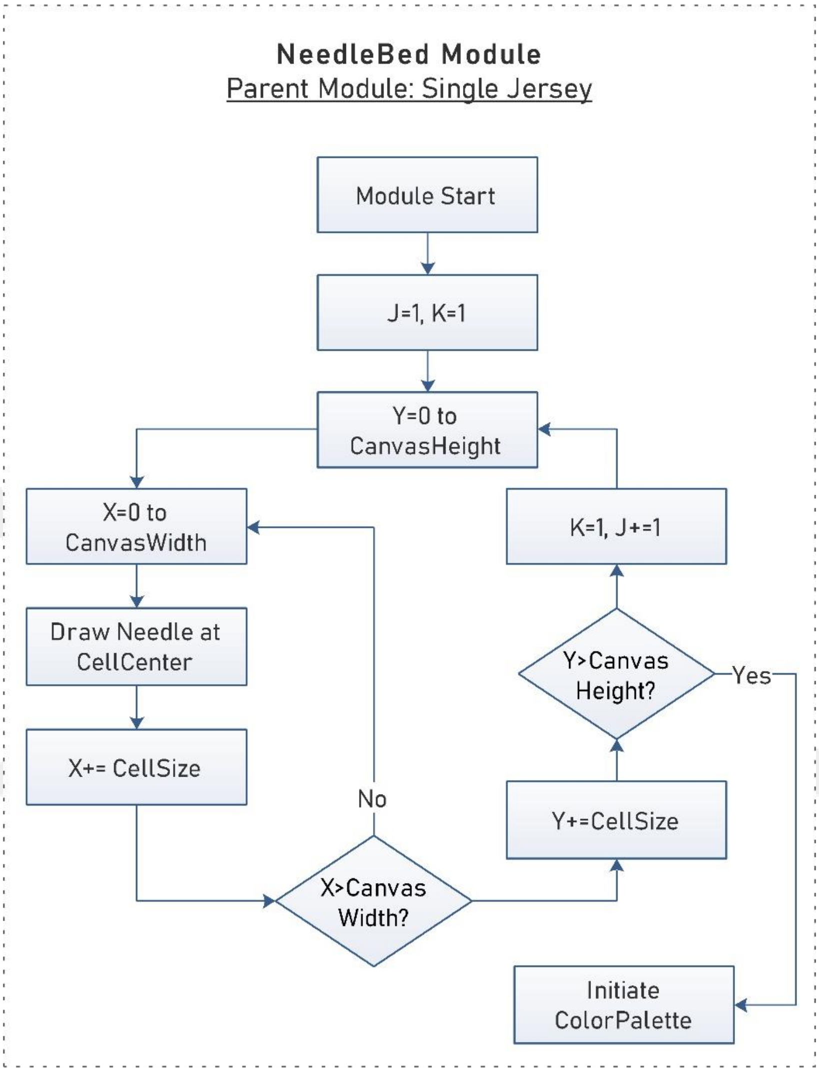


Figure appx-1.7. Algorithm for needle bed in single jersey

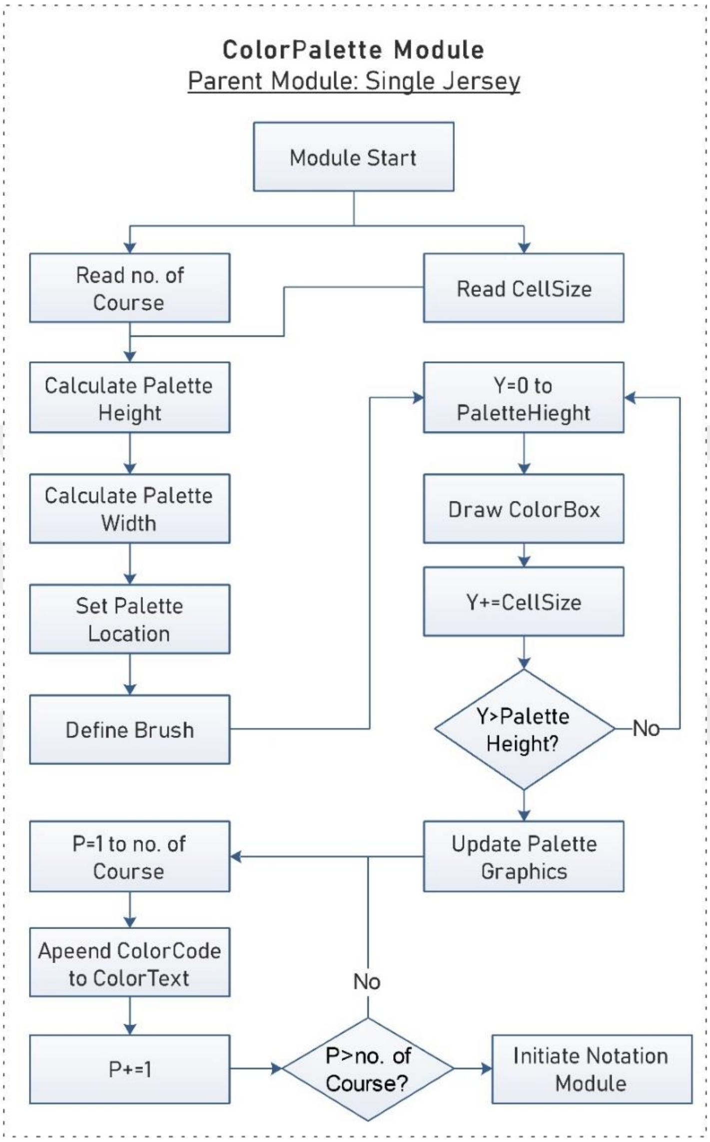


Figure appx-1.8. Algorithm for color palette module in single jersey

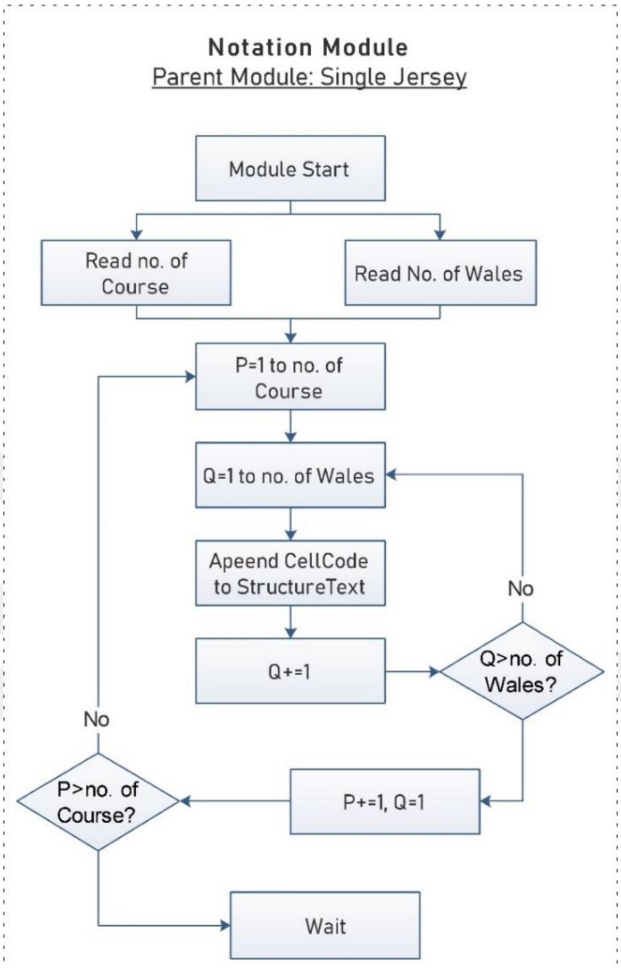


Figure appx-1.9. Algorithm for notation module in single jersey

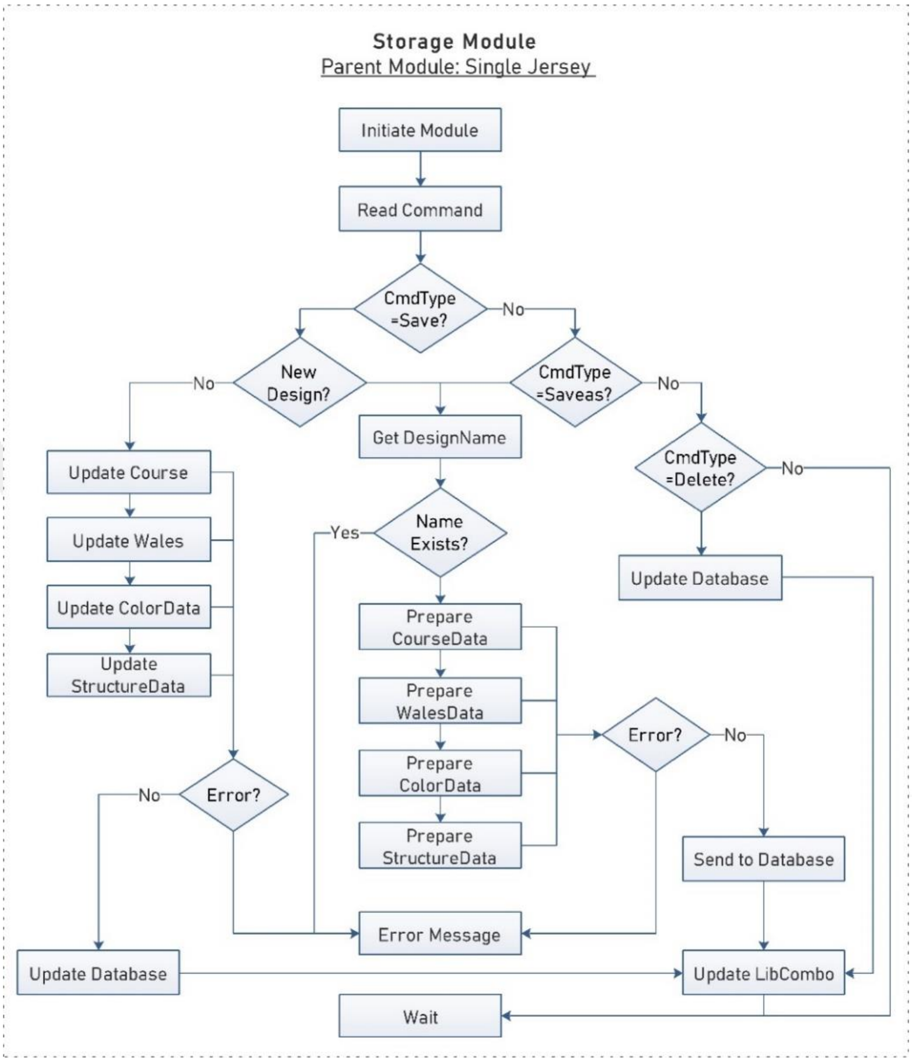


Figure appx-1.10. Algorithm for storage module in single jersey

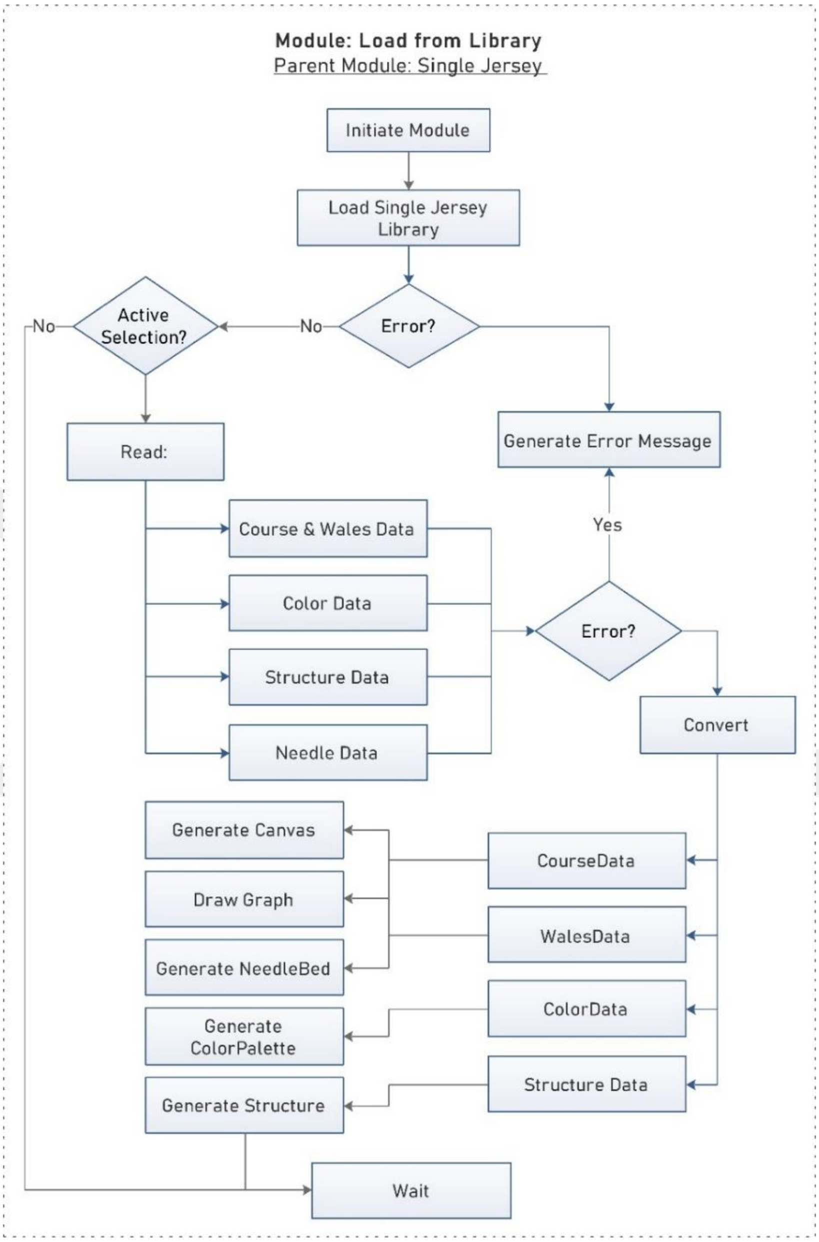


Figure appx-1.11. Algorithm for calling structure from library

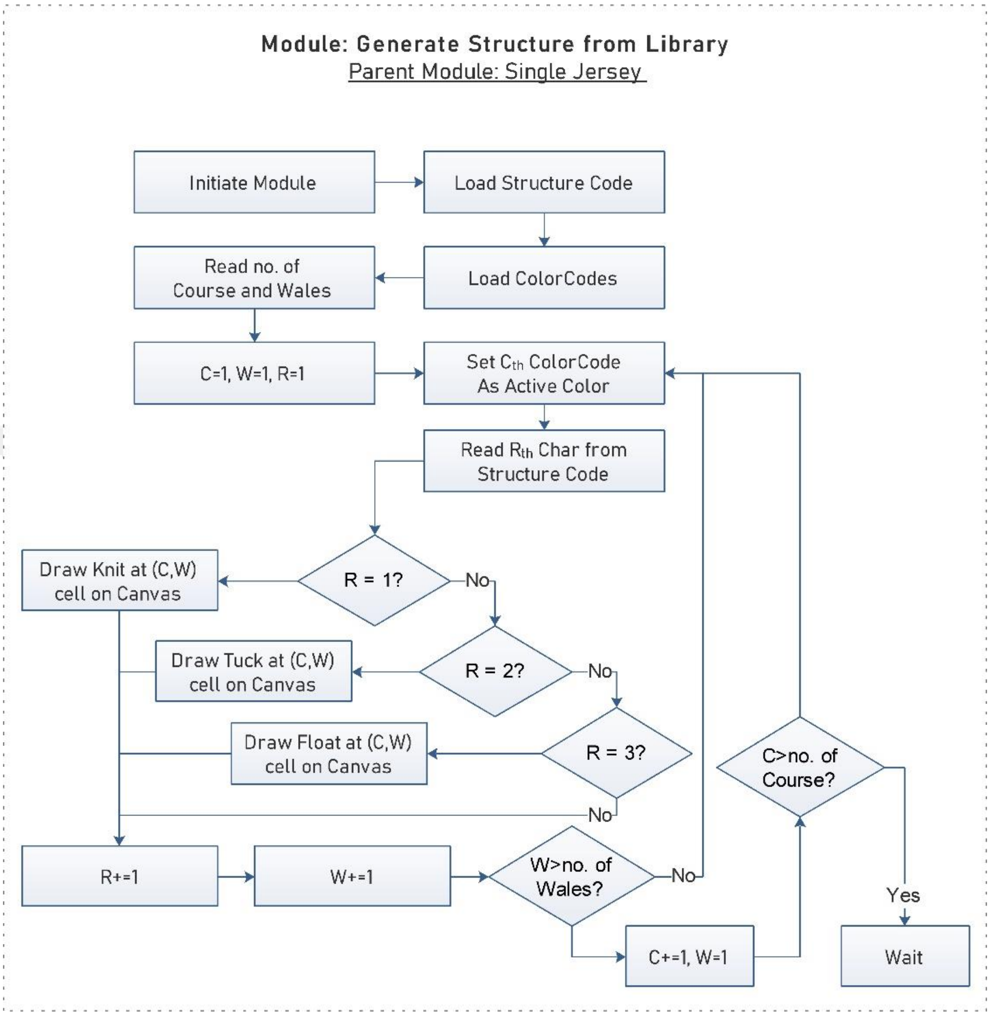


Figure appx-1.12. Algorithm for converting code to notation in single jersey

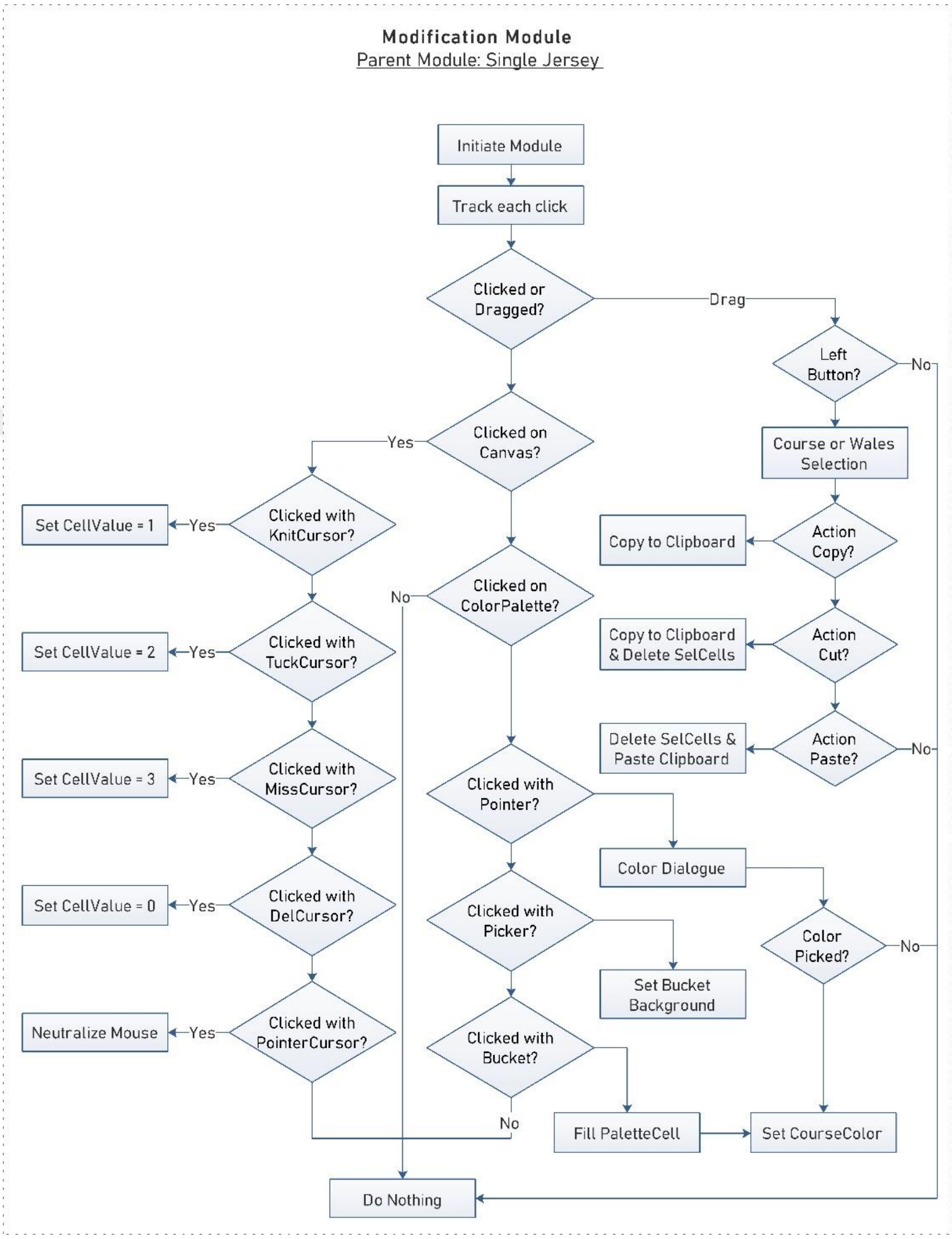


Figure appx-1.13. Algorithm for modification of single jersey structures

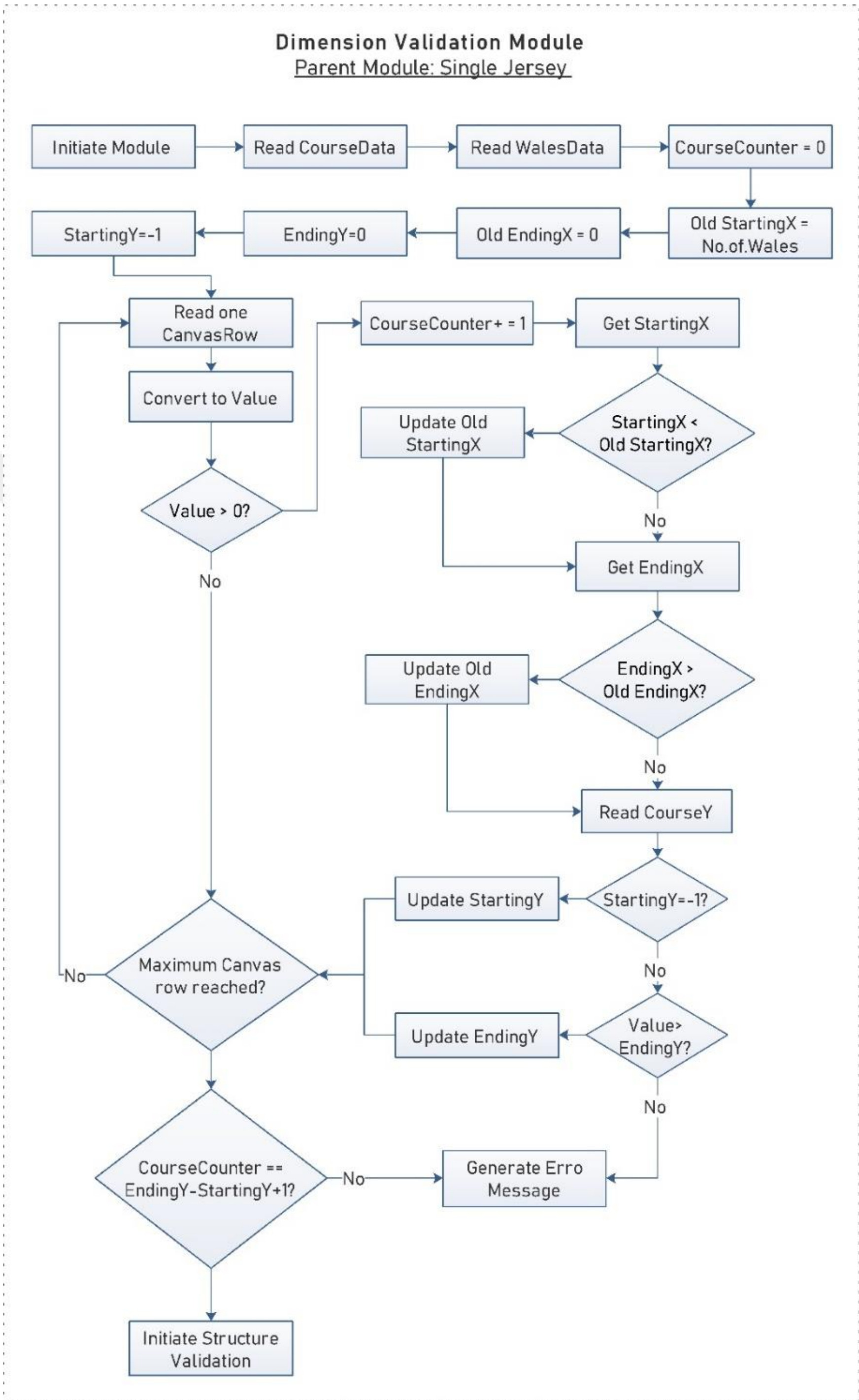


Figure appx-1.14. Algorithm for dimensional validation of single jersey

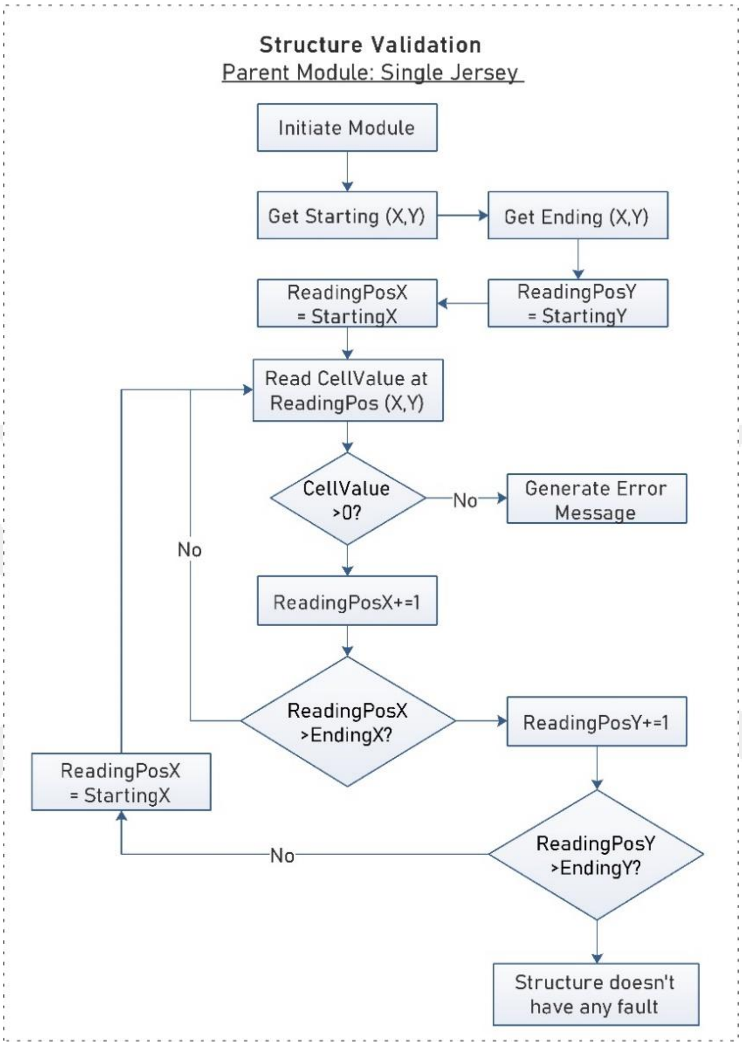


Figure appx-1.15. Algorithm for structural validation of single jersey

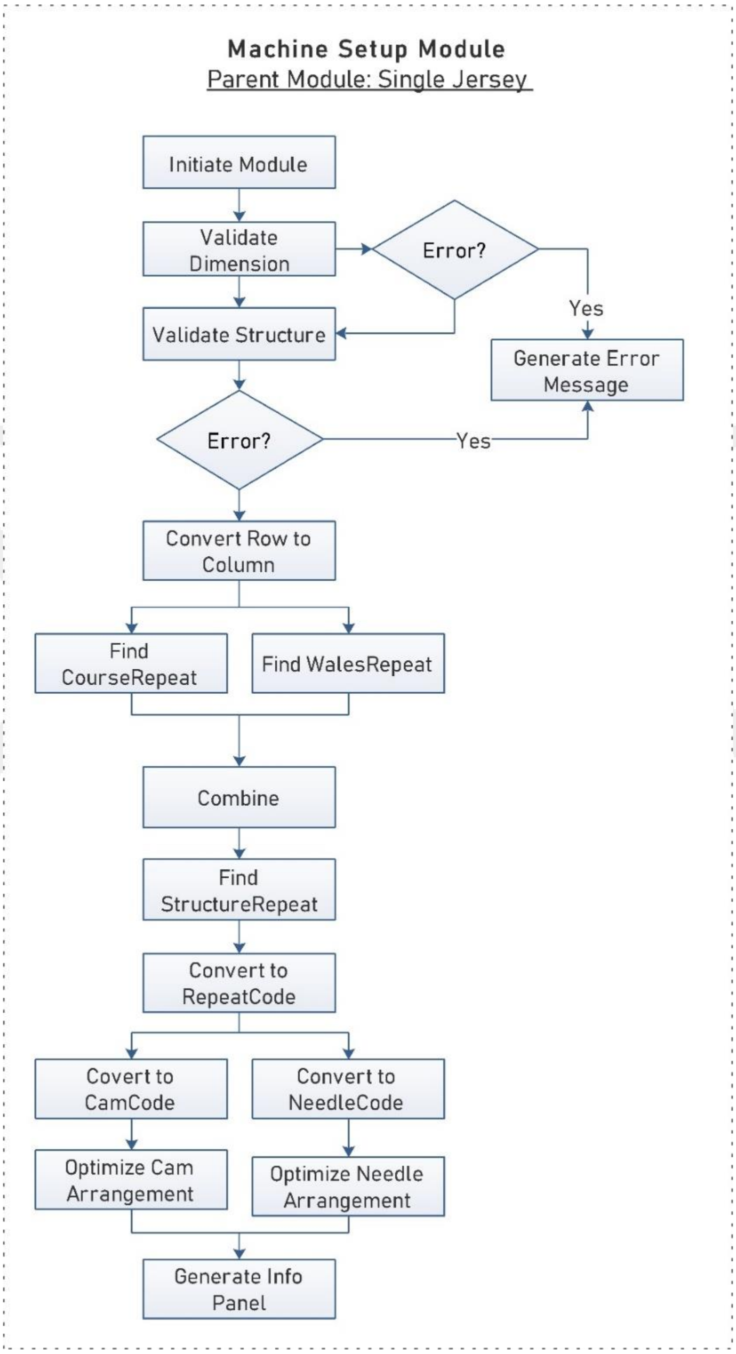


Figure appx-1.16. Algorithm for identifying machine setup in single jersey

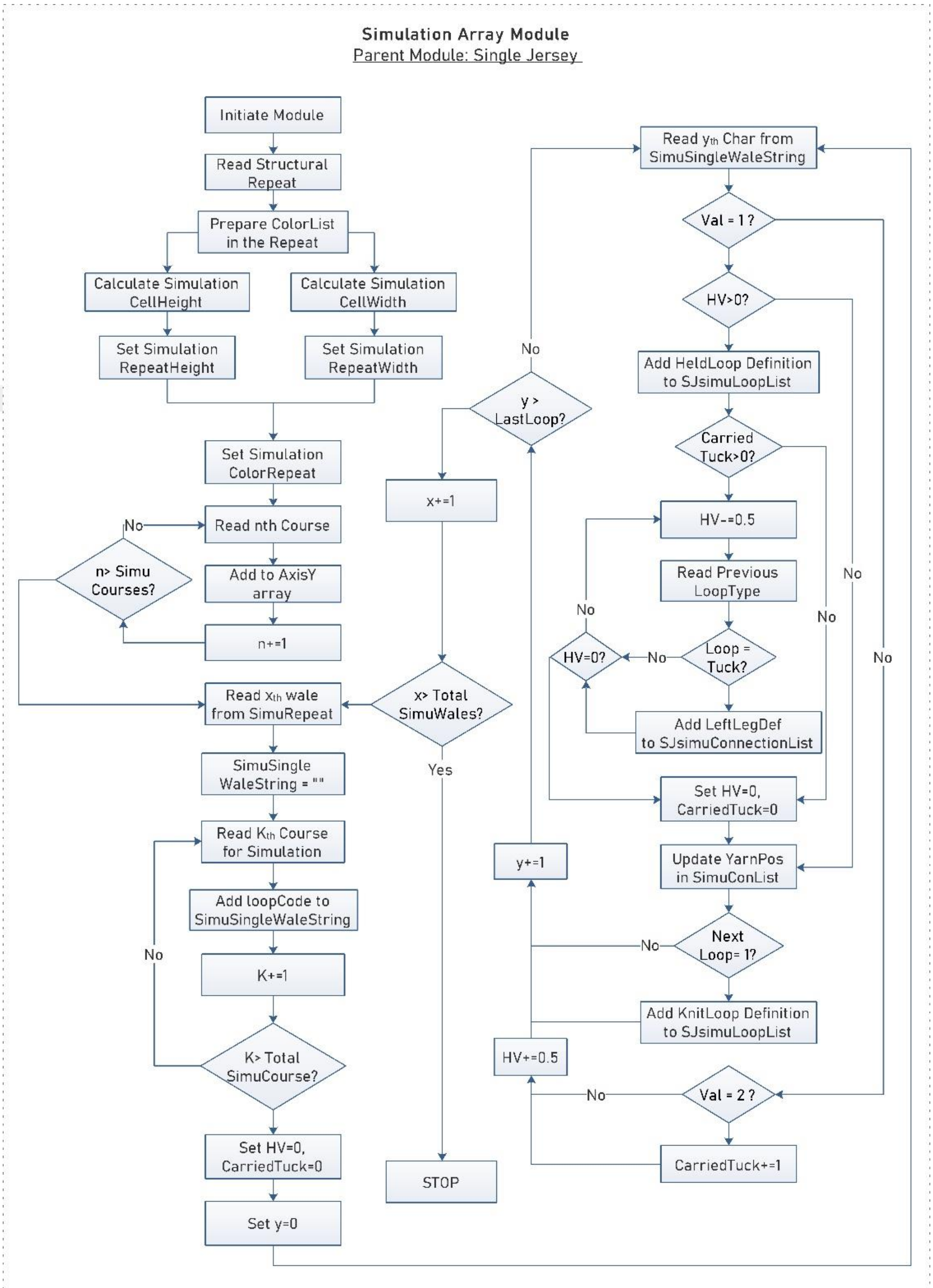


Figure appx-1.17. Algorithm for simulation array in single jersey

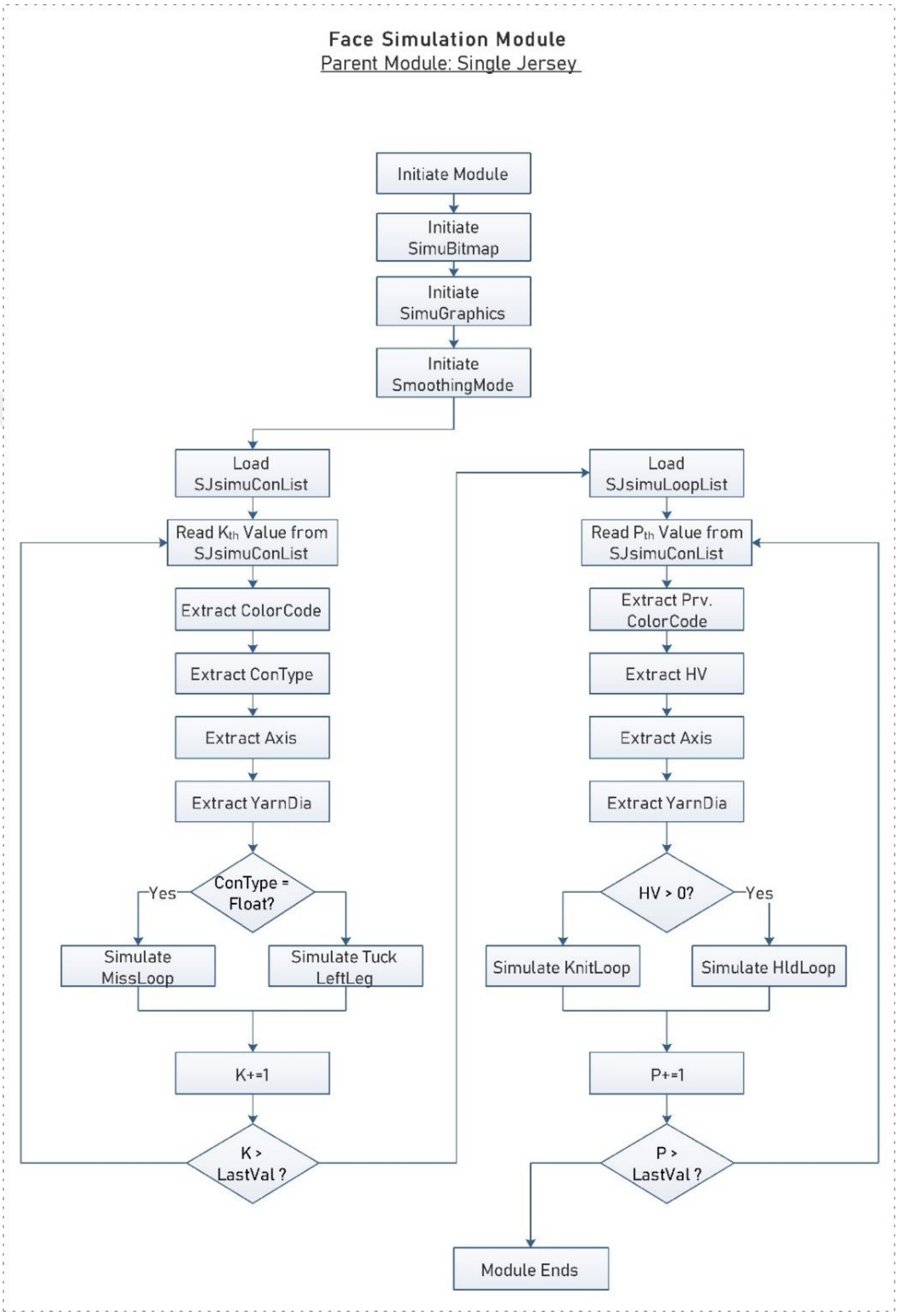


Figure appx-1.18. Algorithm for simulating technical face of single jersey

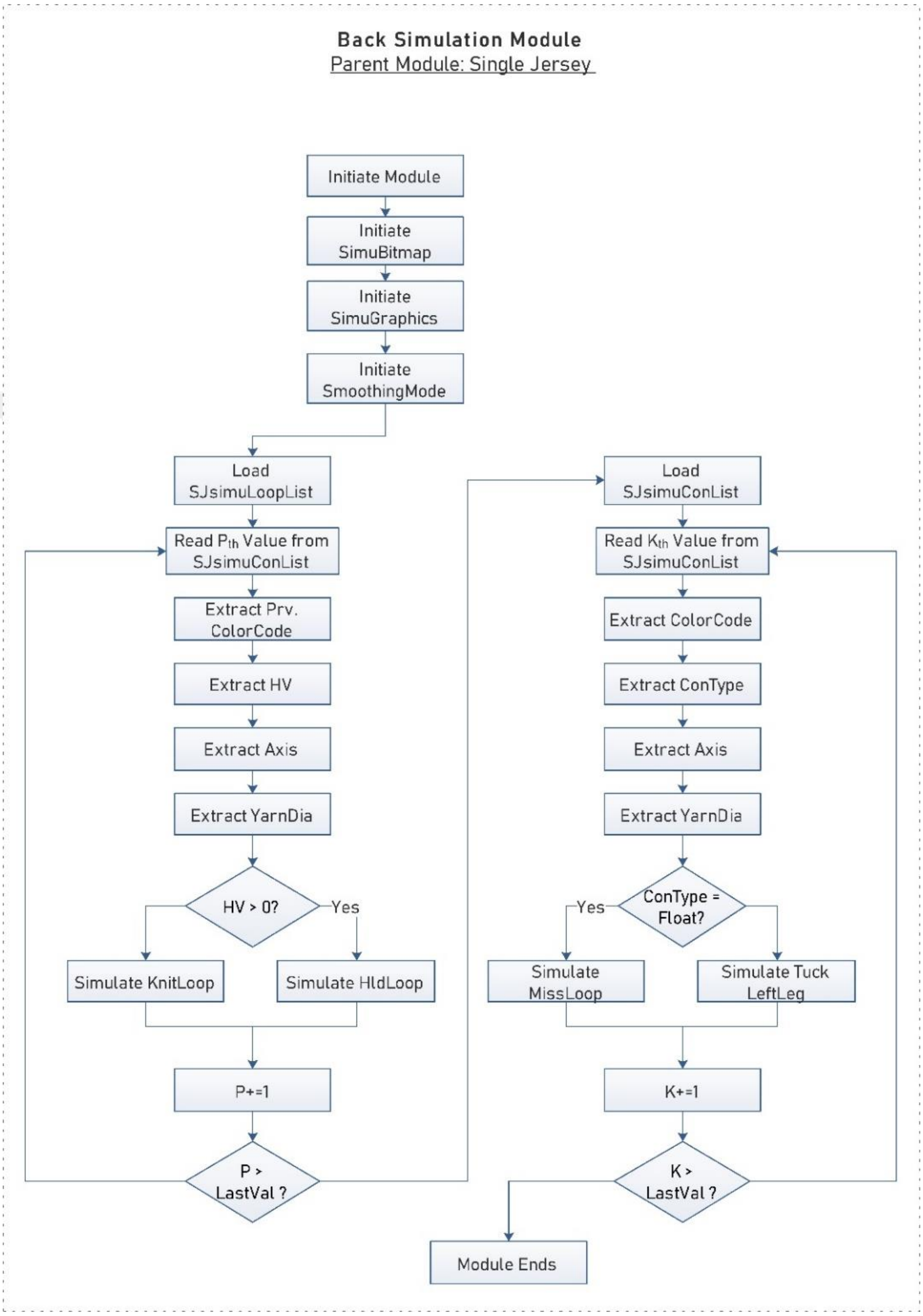


Figure appx-1.19. Algorithm for simulating technical back of single jersey

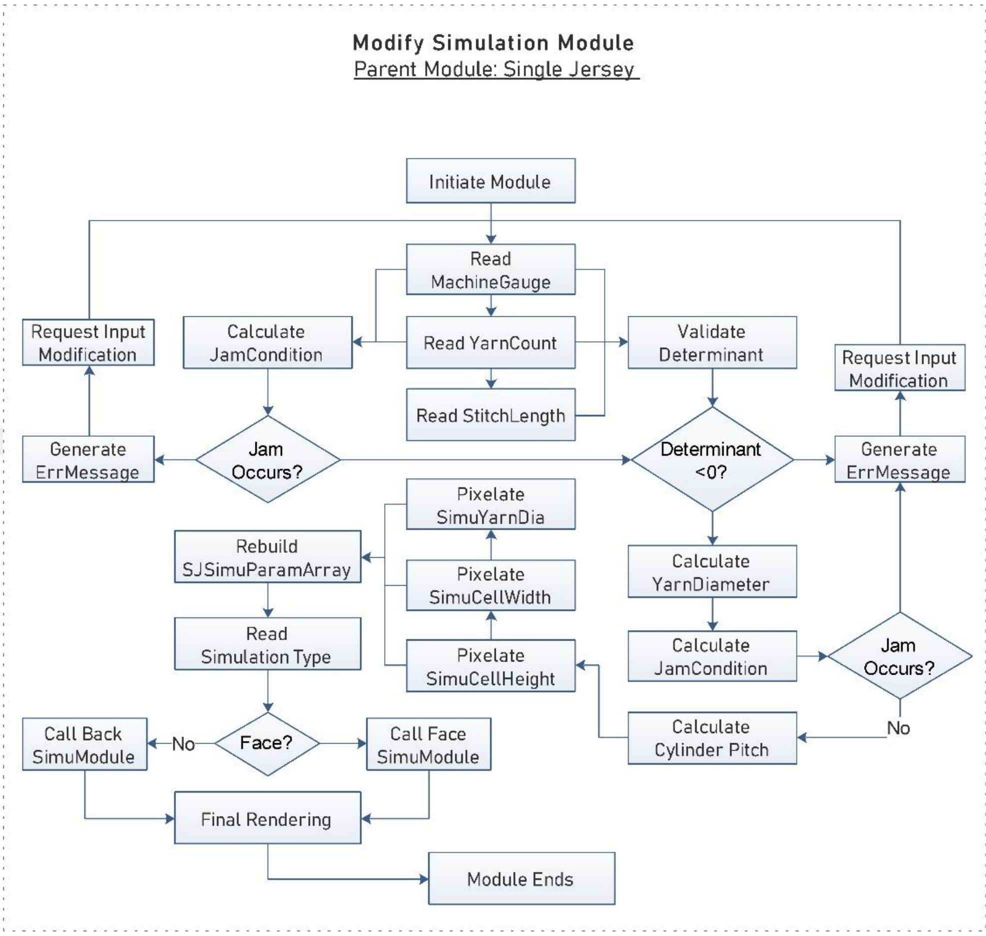


Figure appx-1.20. Algorithm for modification of single jersey simulation

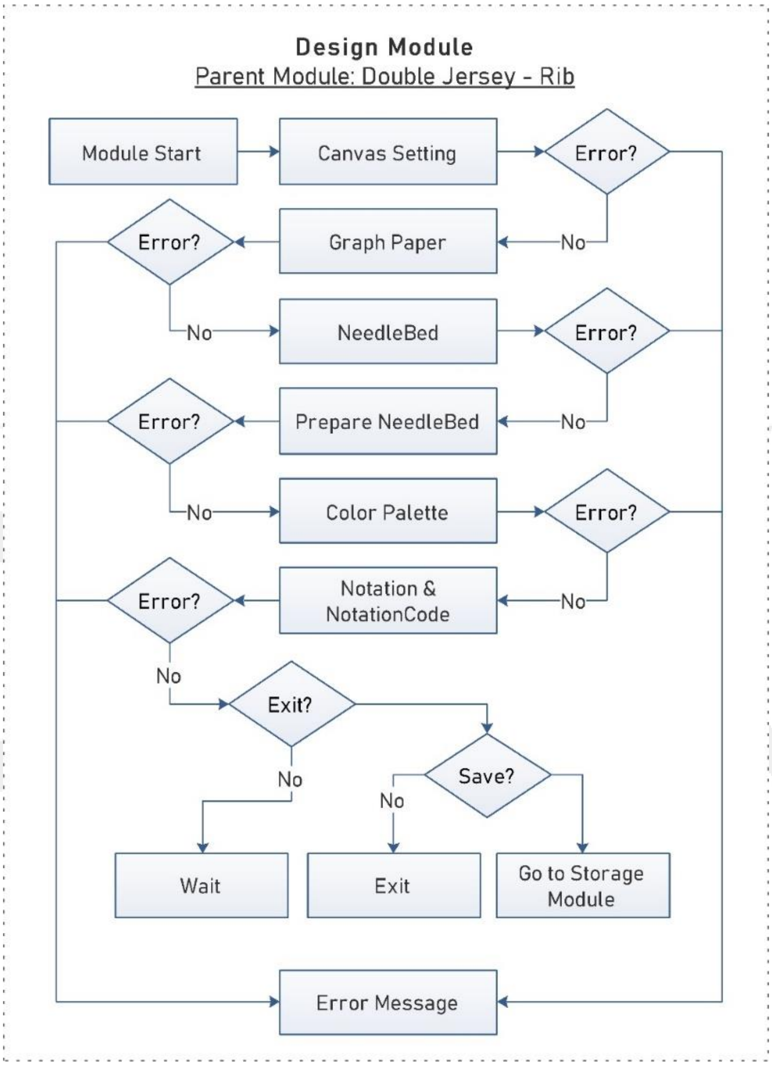


Figure appx-1.21. Algorithm for the design module of Rib

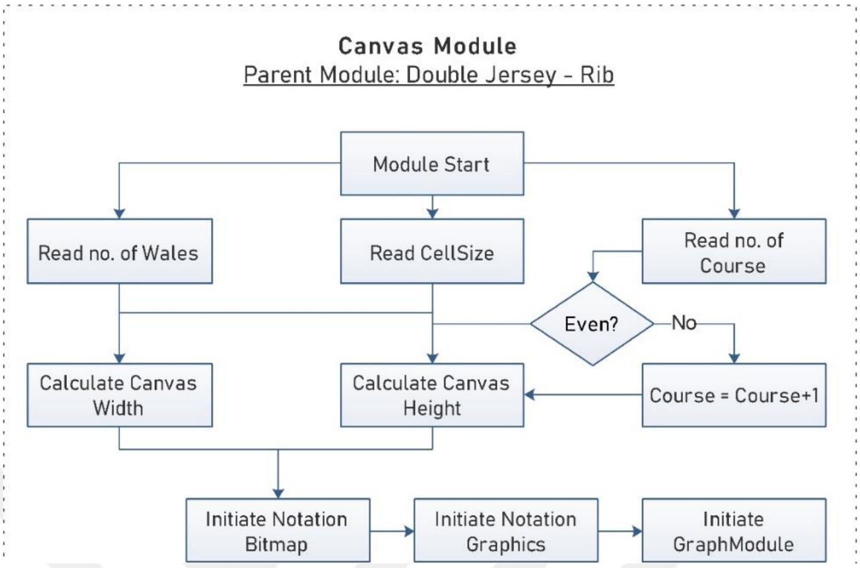


Figure appx-1.22. Algorithm for the canvas module of Rib

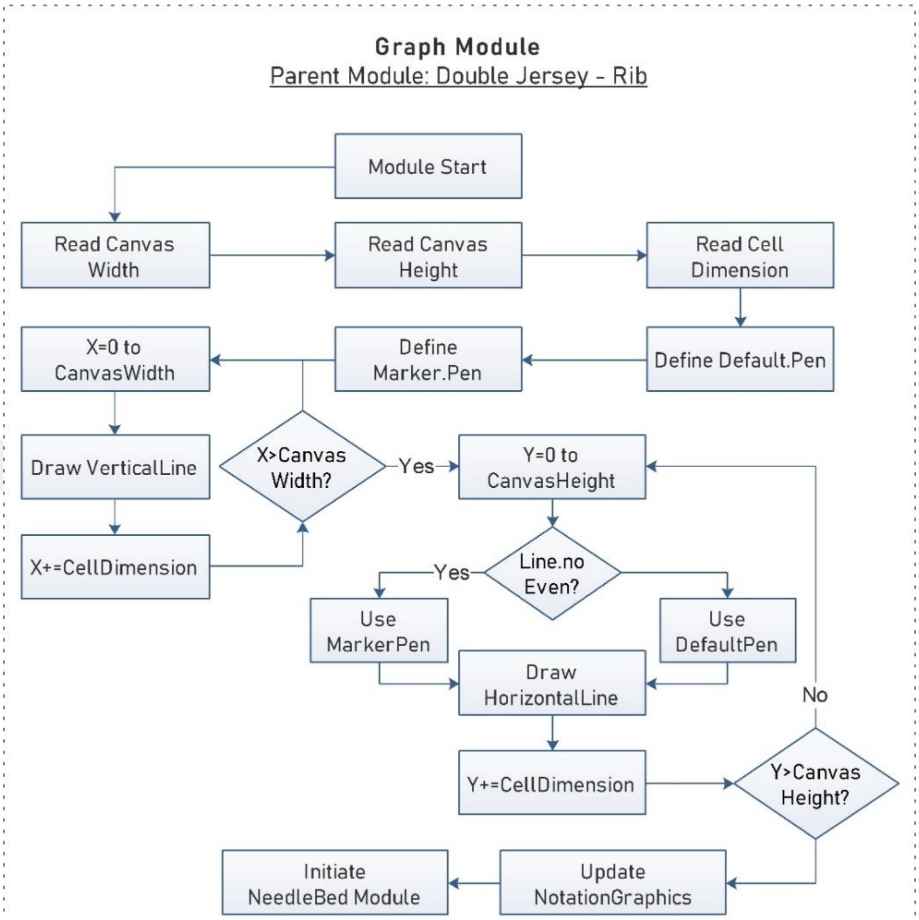


Figure appx-1.23. Algorithm for the graph module of Rib

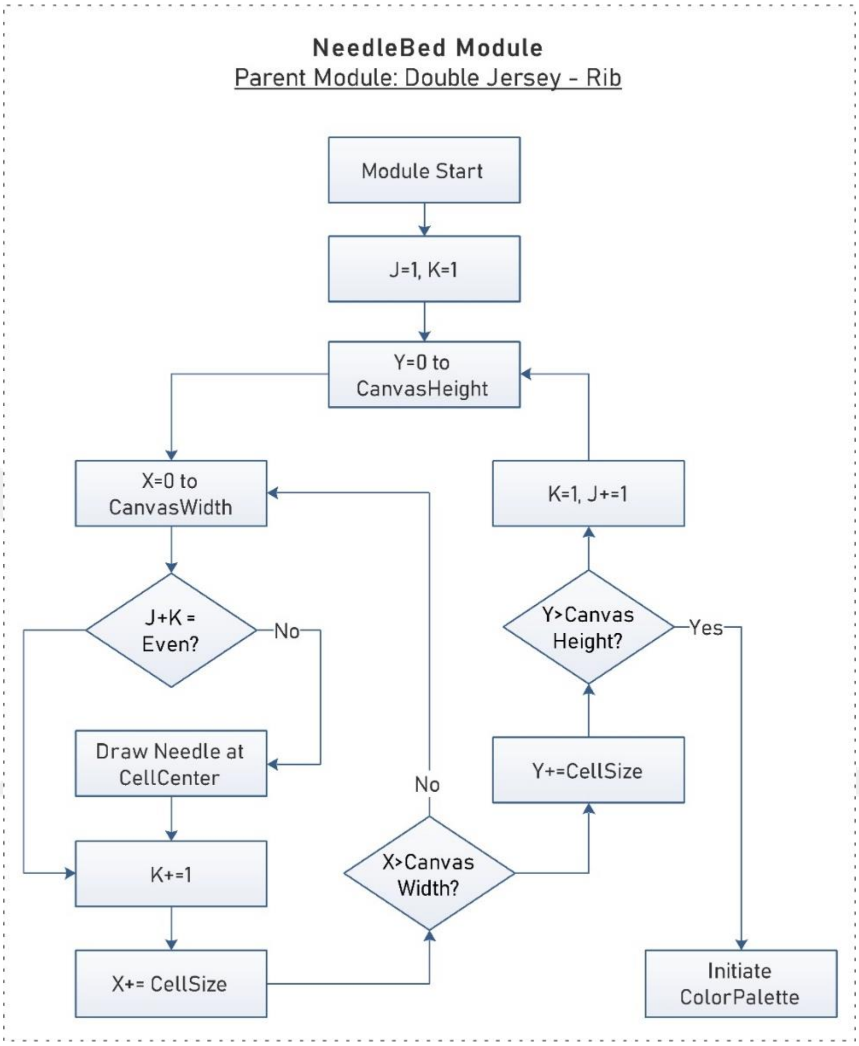


Figure appx-1.24. Algorithm for the Needle Bed module of Rib

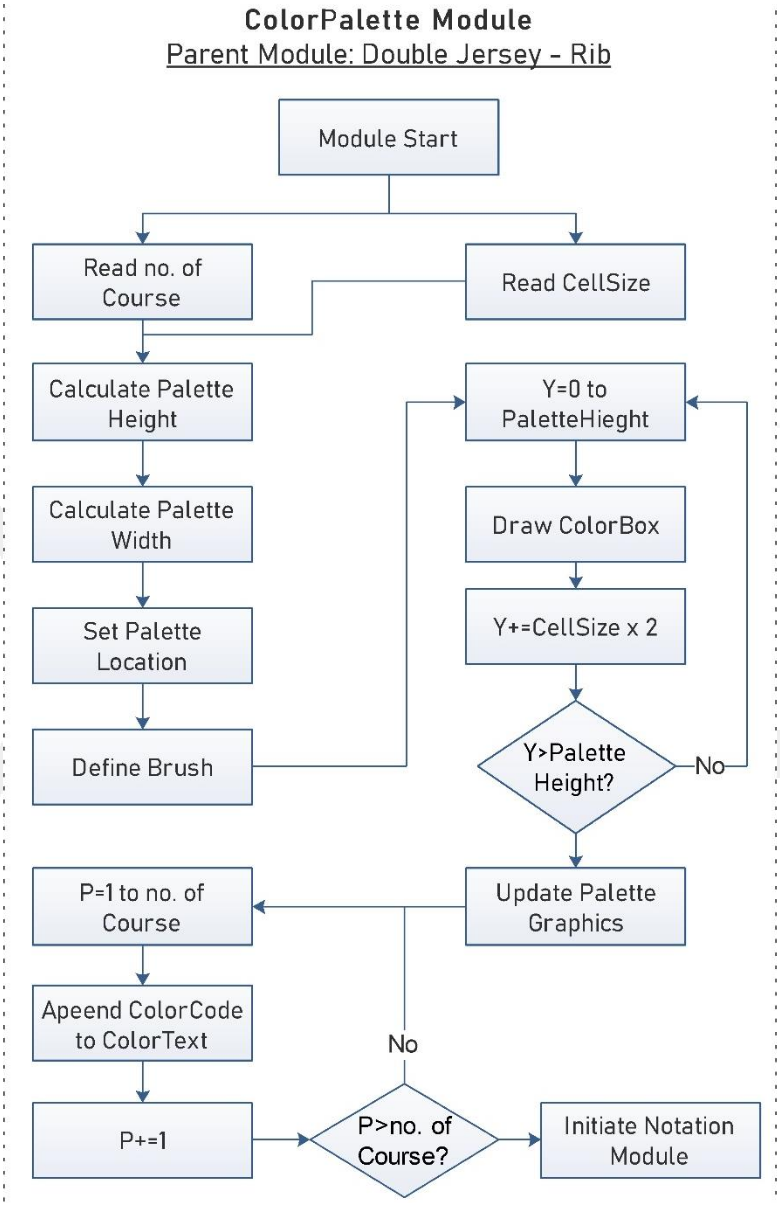


Figure appx-1.25. Algorithm for the Color module of Rib

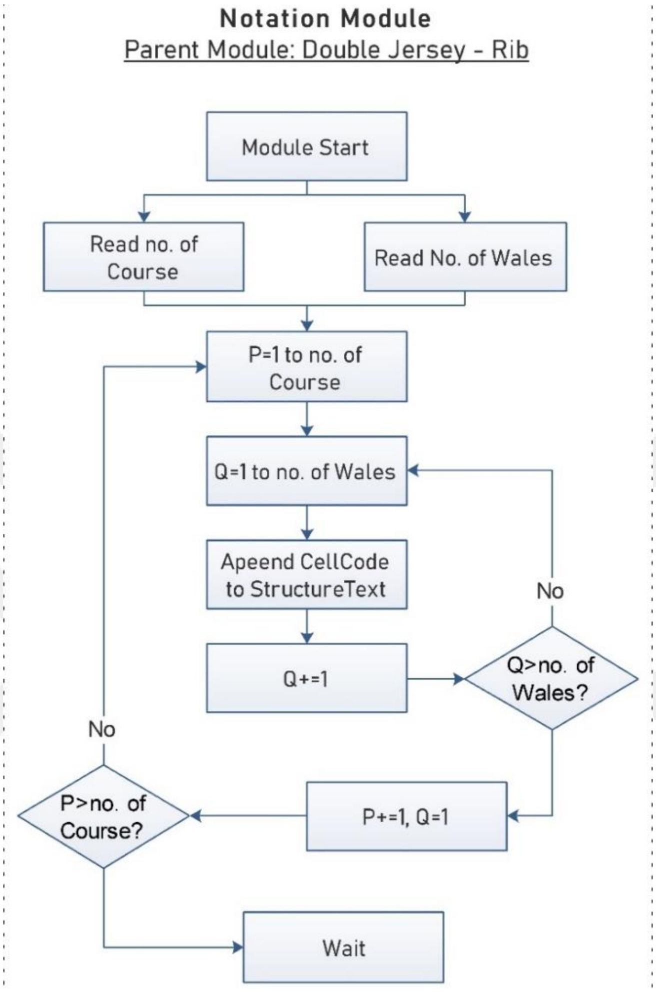


Figure appx-1.26. Algorithm for the Notation module of Rib

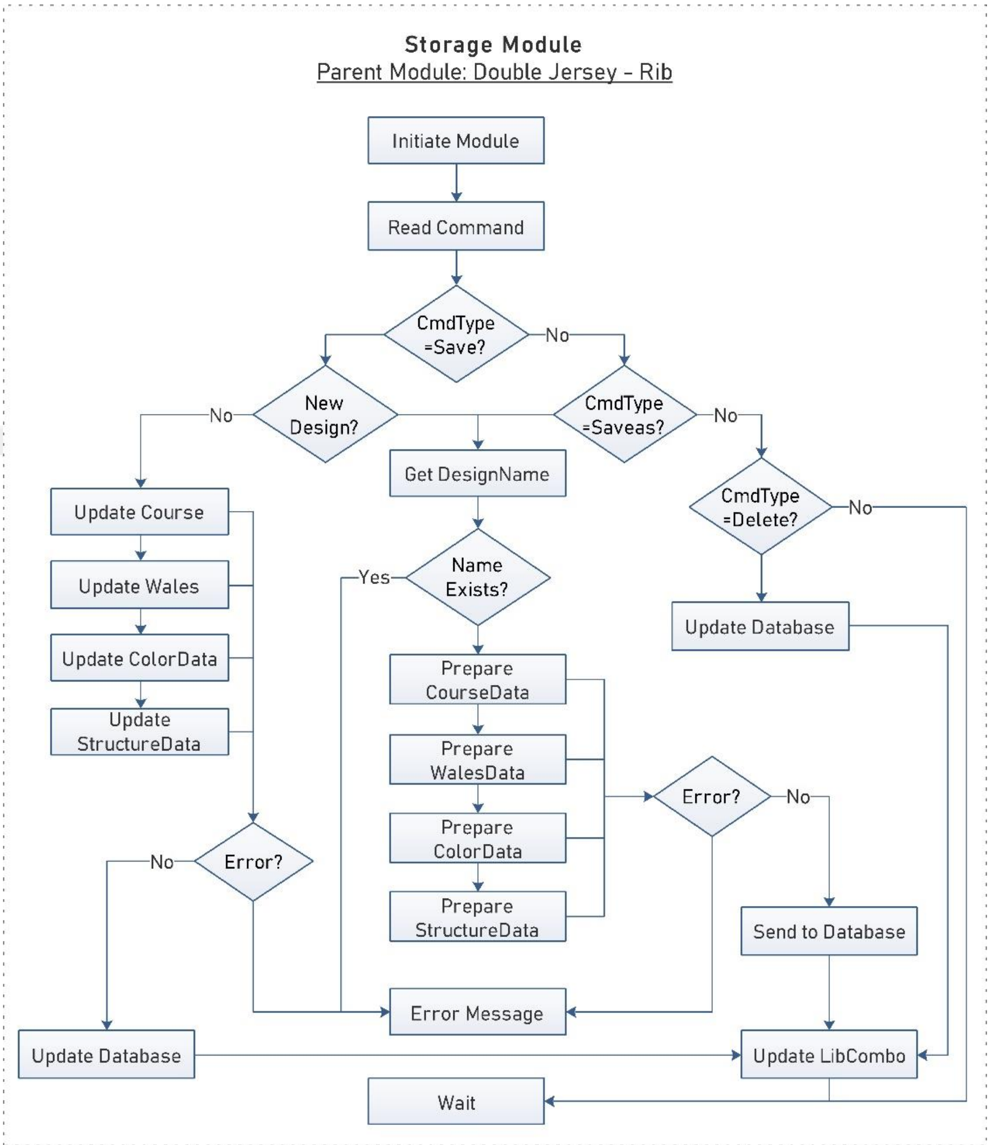


Figure appx-1.27. Algorithm for the Storage module of Rib

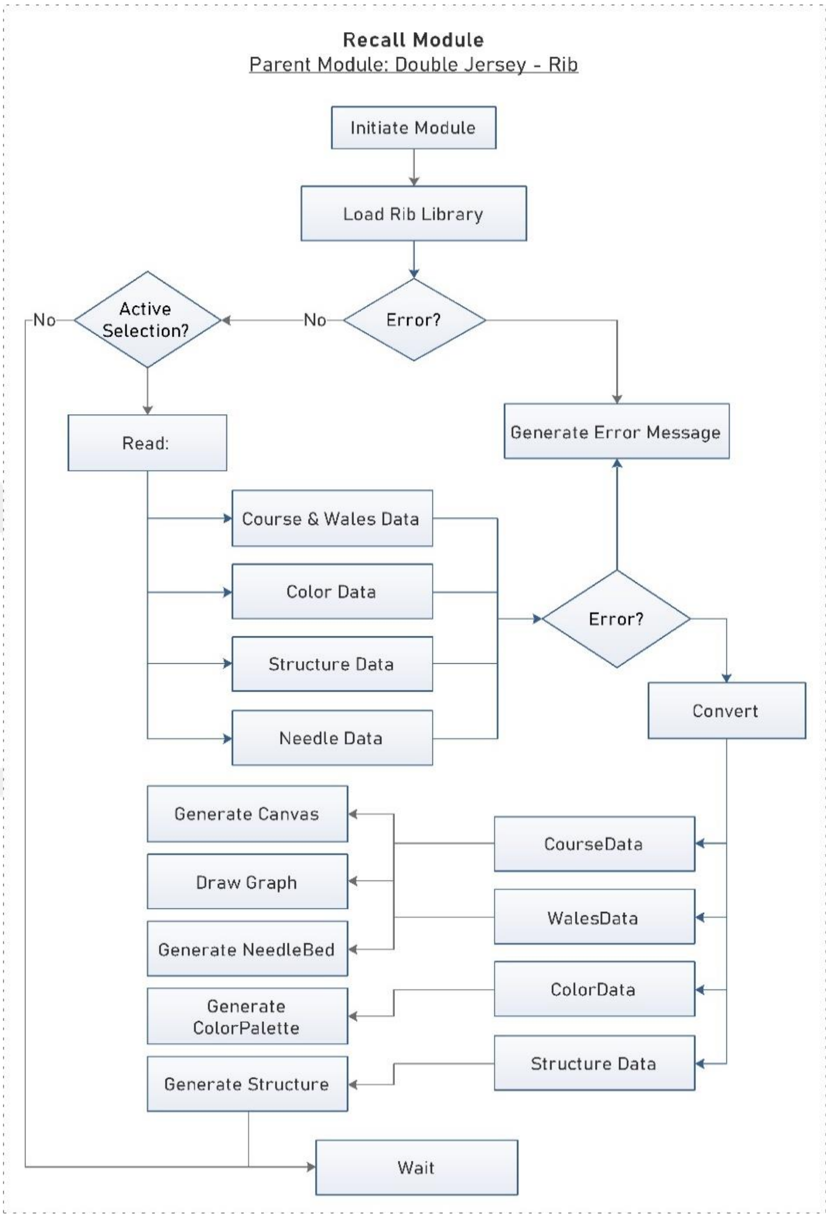


Figure appx-1.28. Algorithm for Recall module of Rib

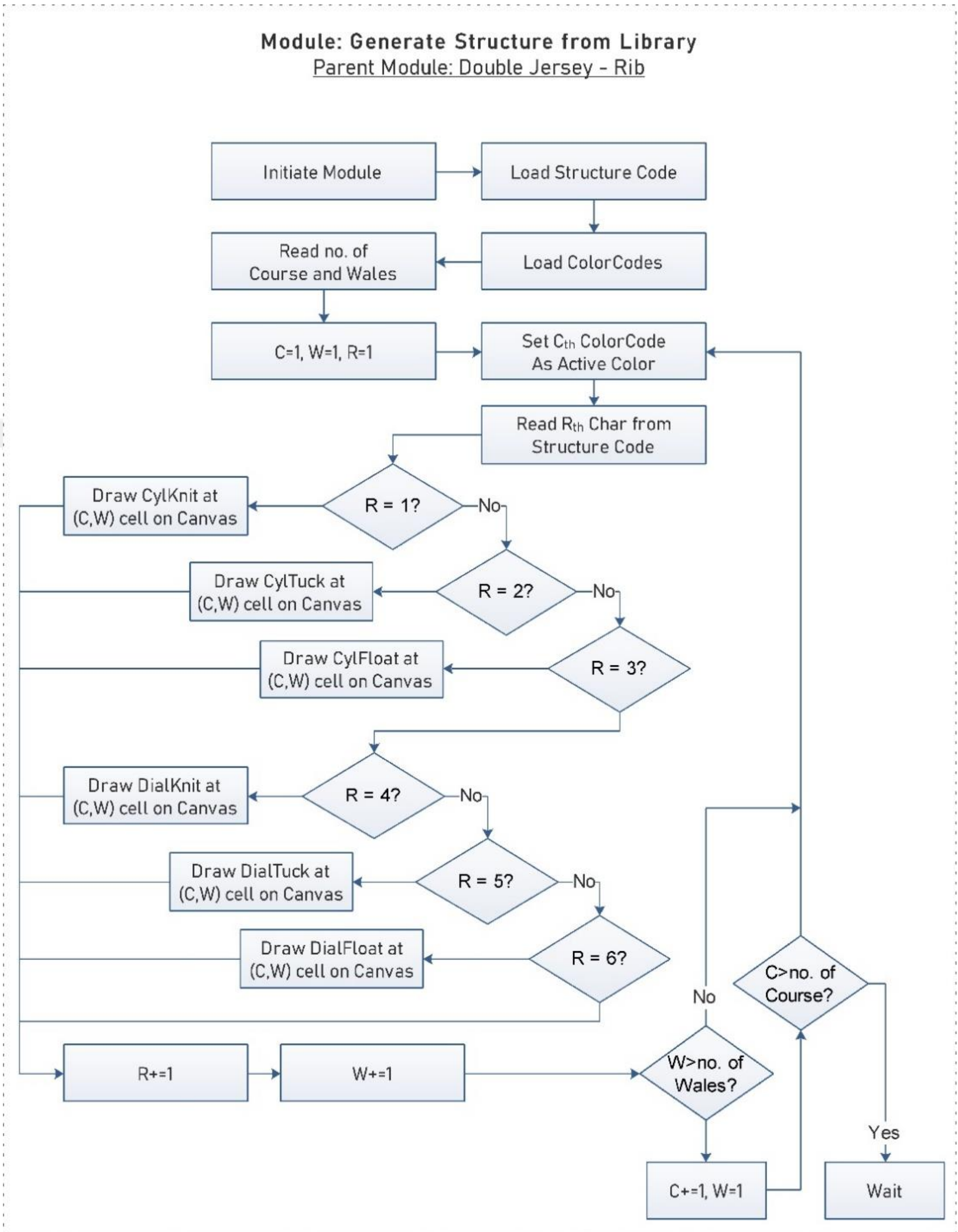


Figure appx-1.29. Algorithm for regenerating structure from library

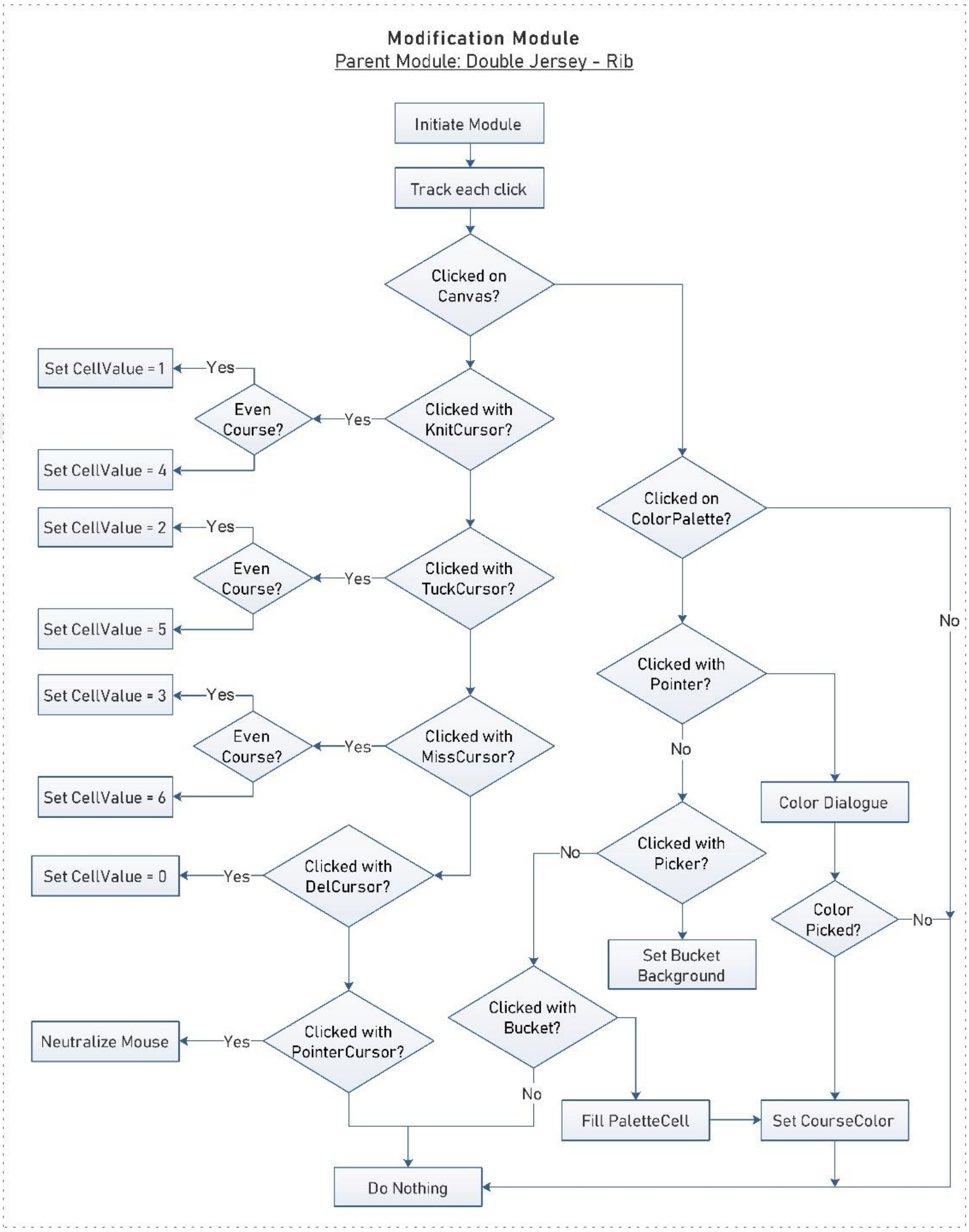


Figure appx-1.30. Algorithm for modifying structure of Rib

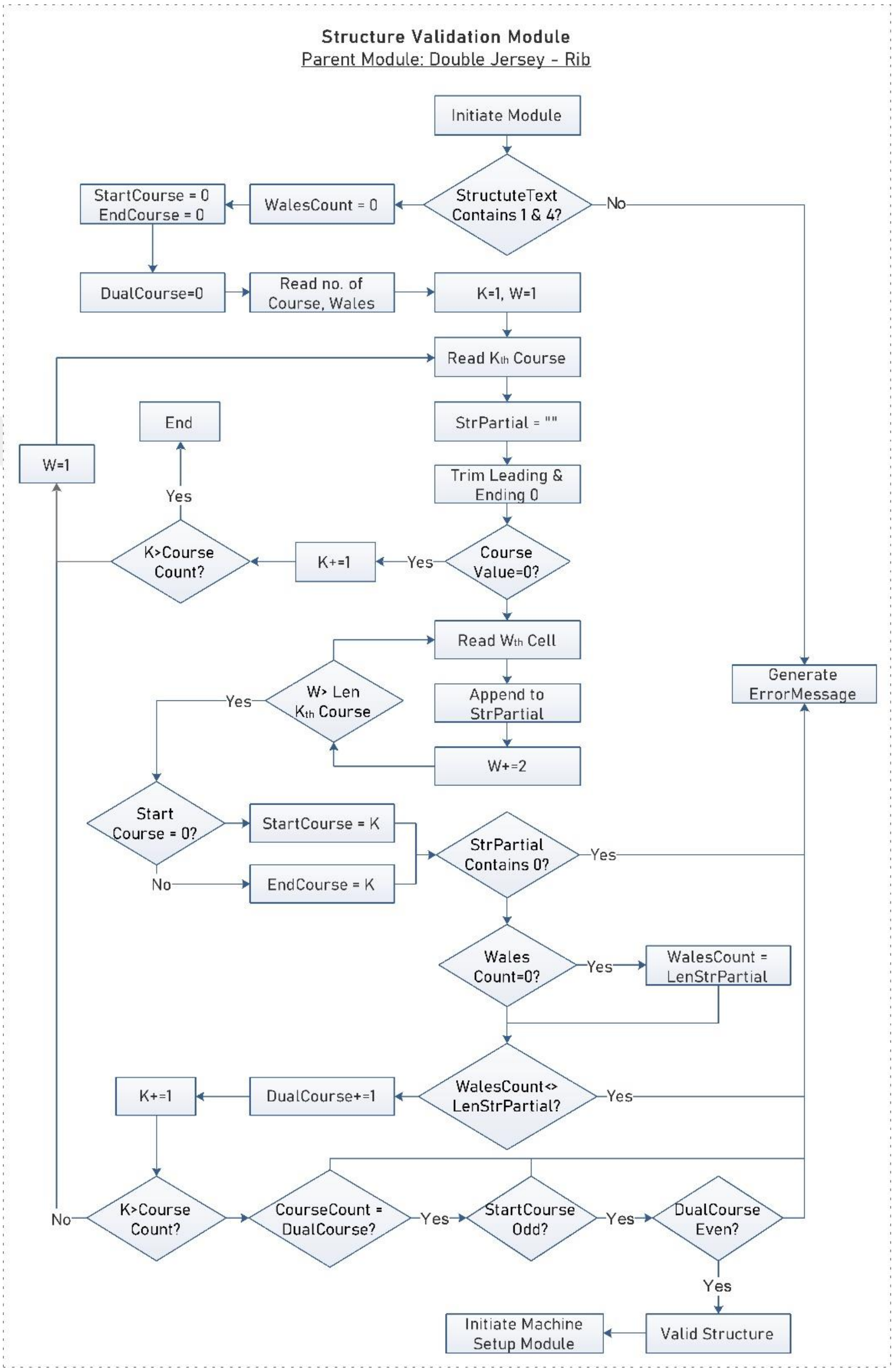


Figure appx-1.31. Algorithm for structure validation of Rib

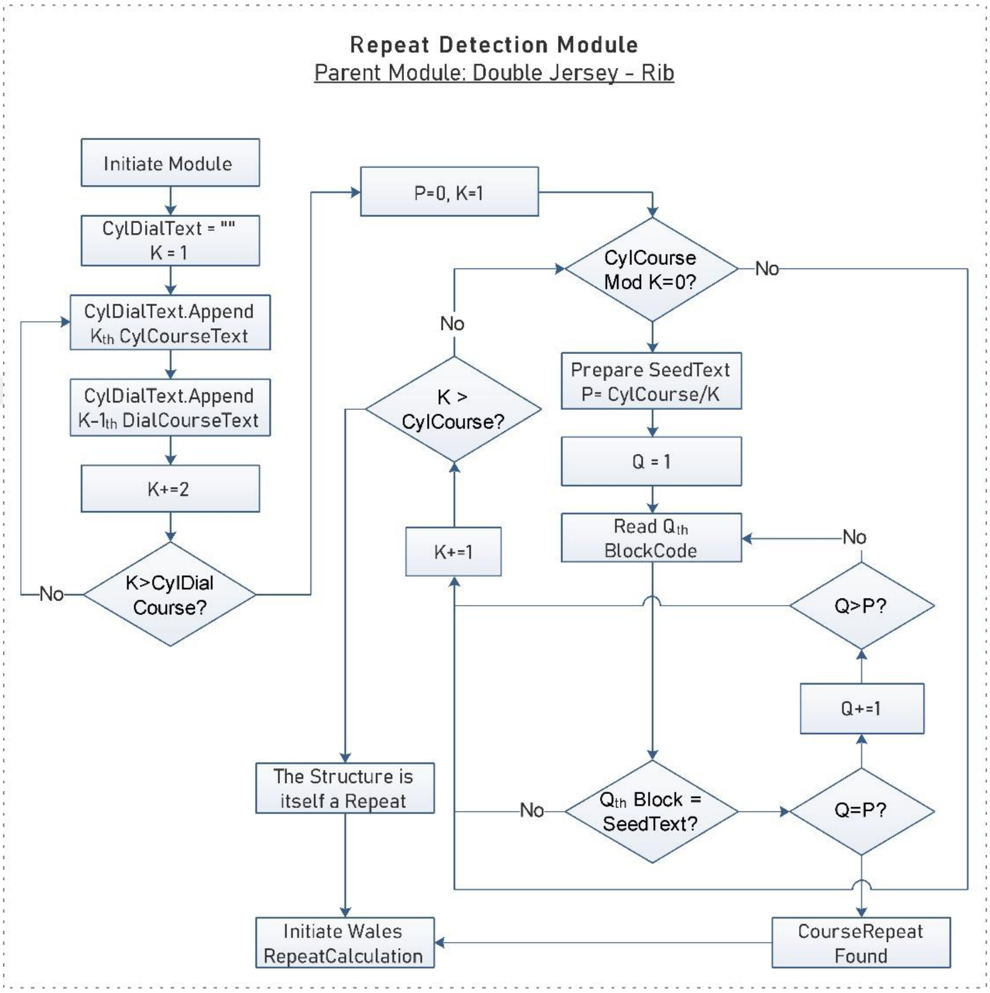


Figure appx-1.32. Algorithm for Repeat calculation of Rib

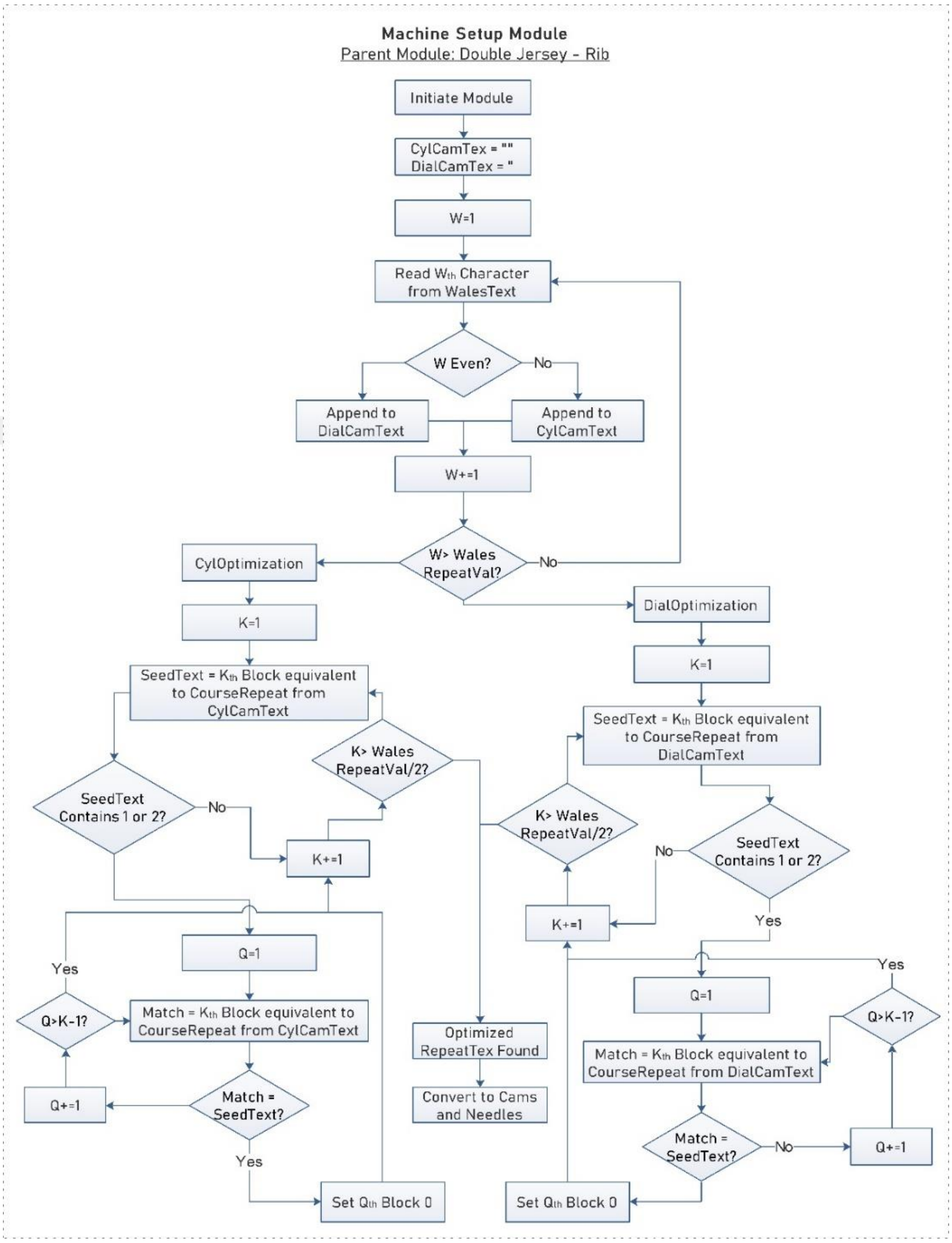


Figure appx-1.33. Algorithm for machine setup of Rib

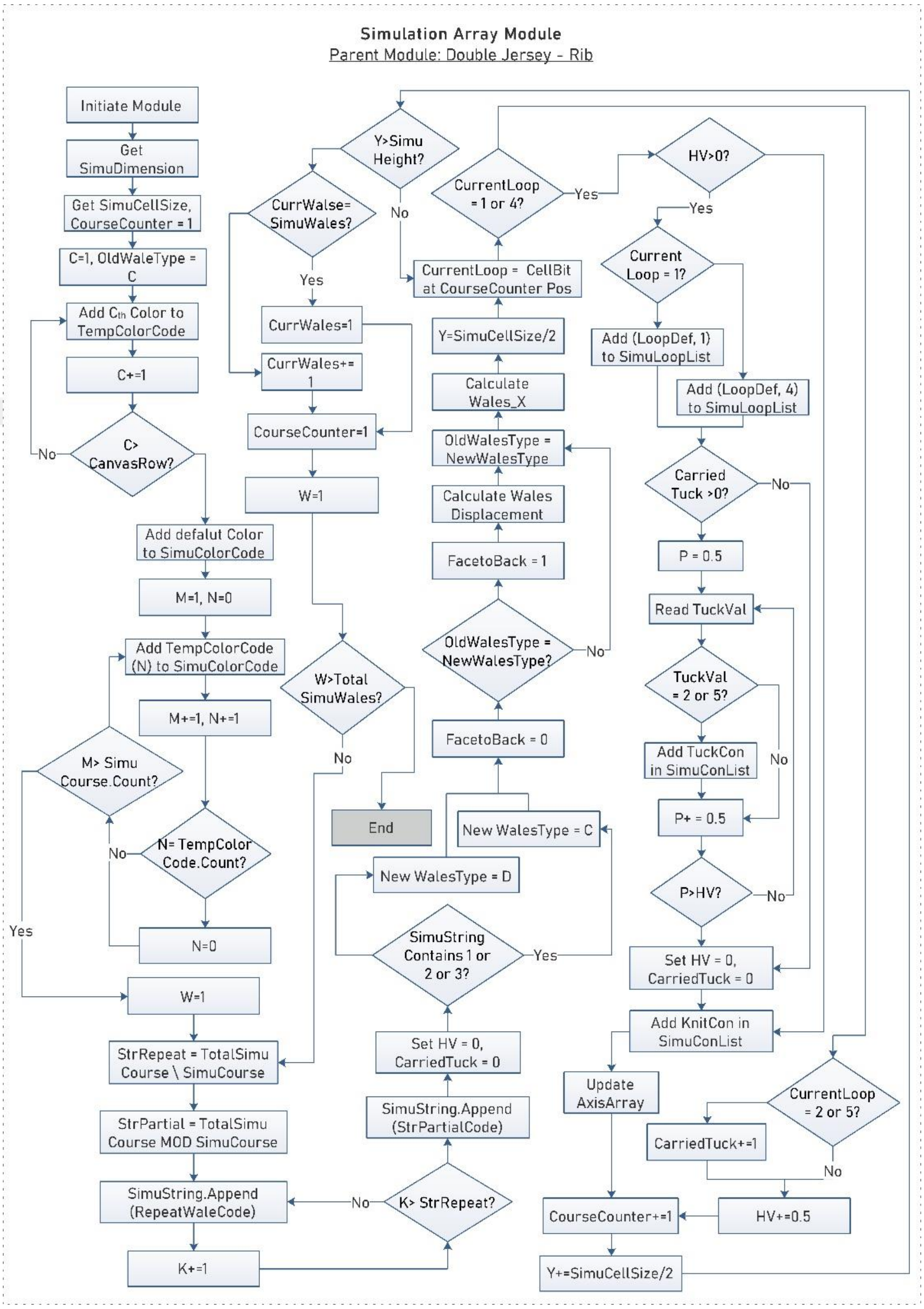


Figure appx-1.34. Simulation array module for Rib

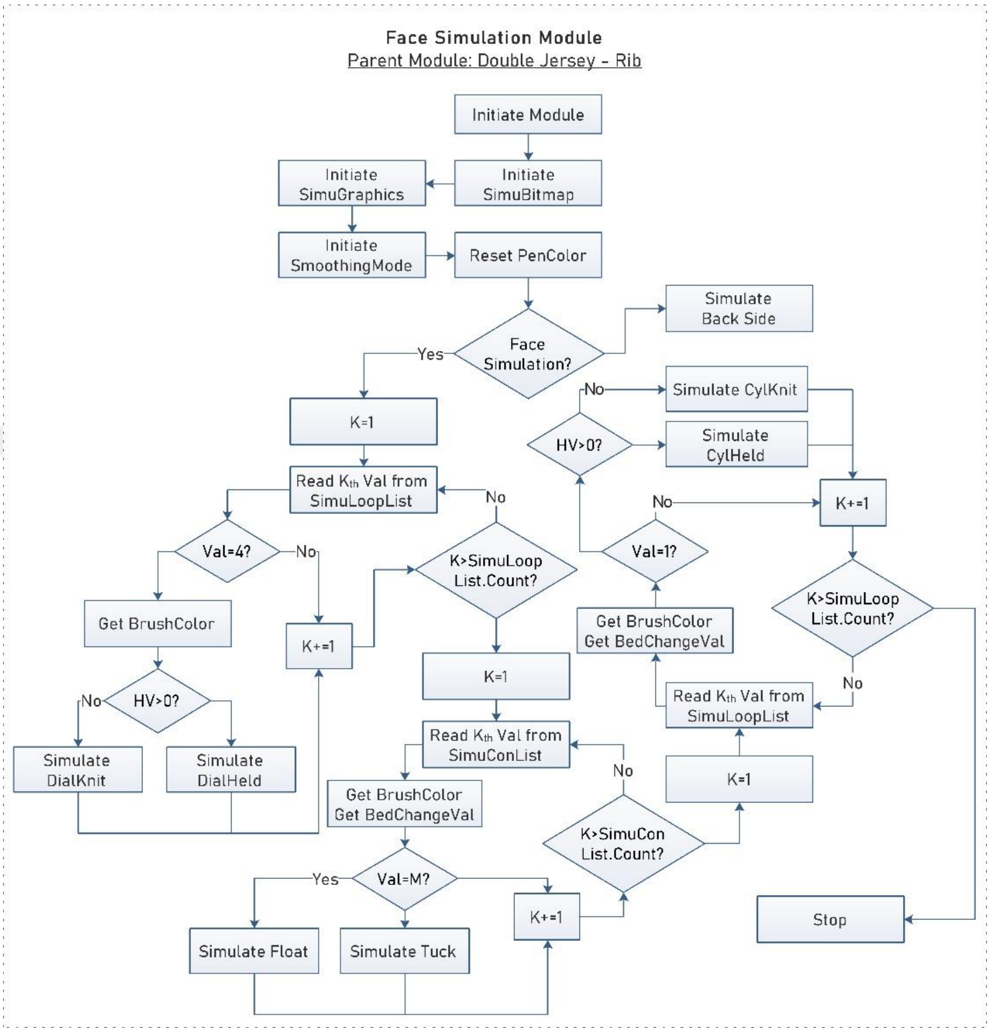


Figure appx-1.35. Algorithm for Face simulation of Rib

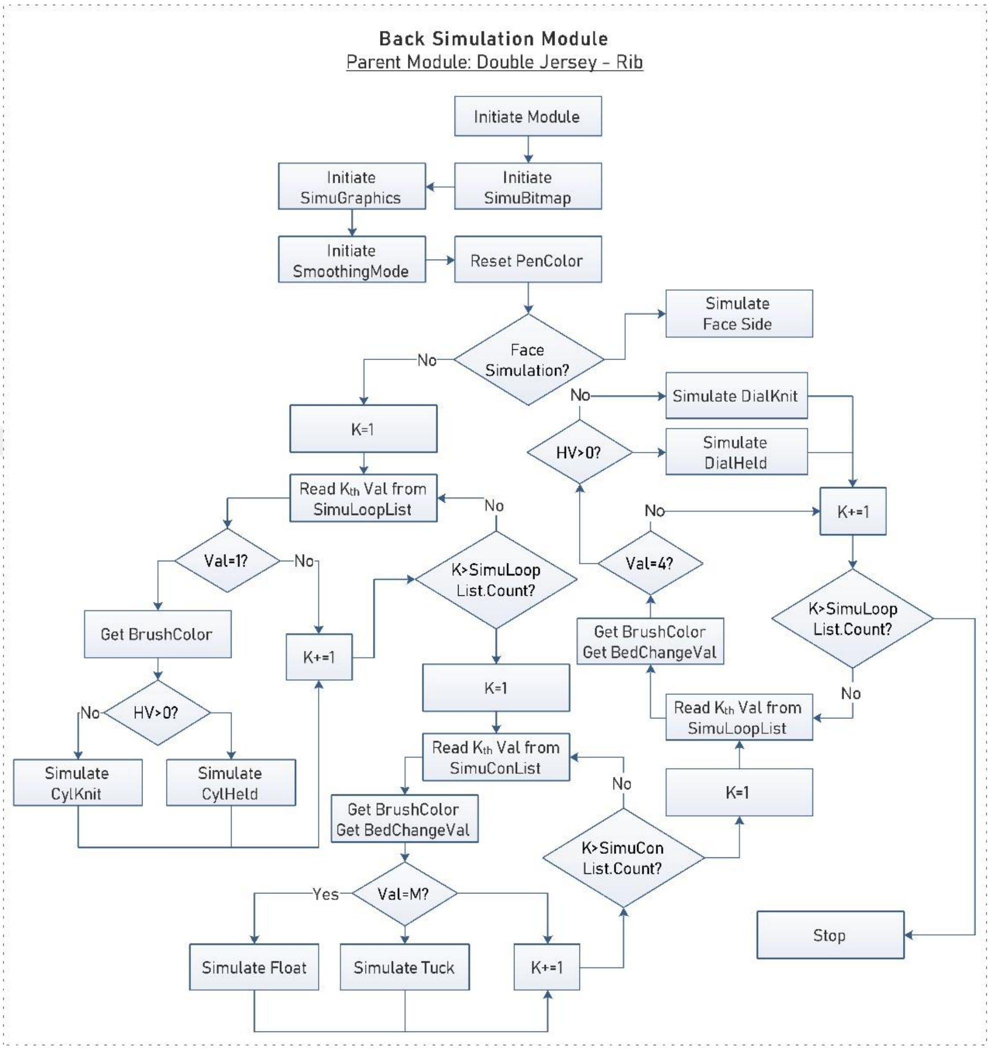


Figure appx-1.36. Algorithm for Back simulation of Rib

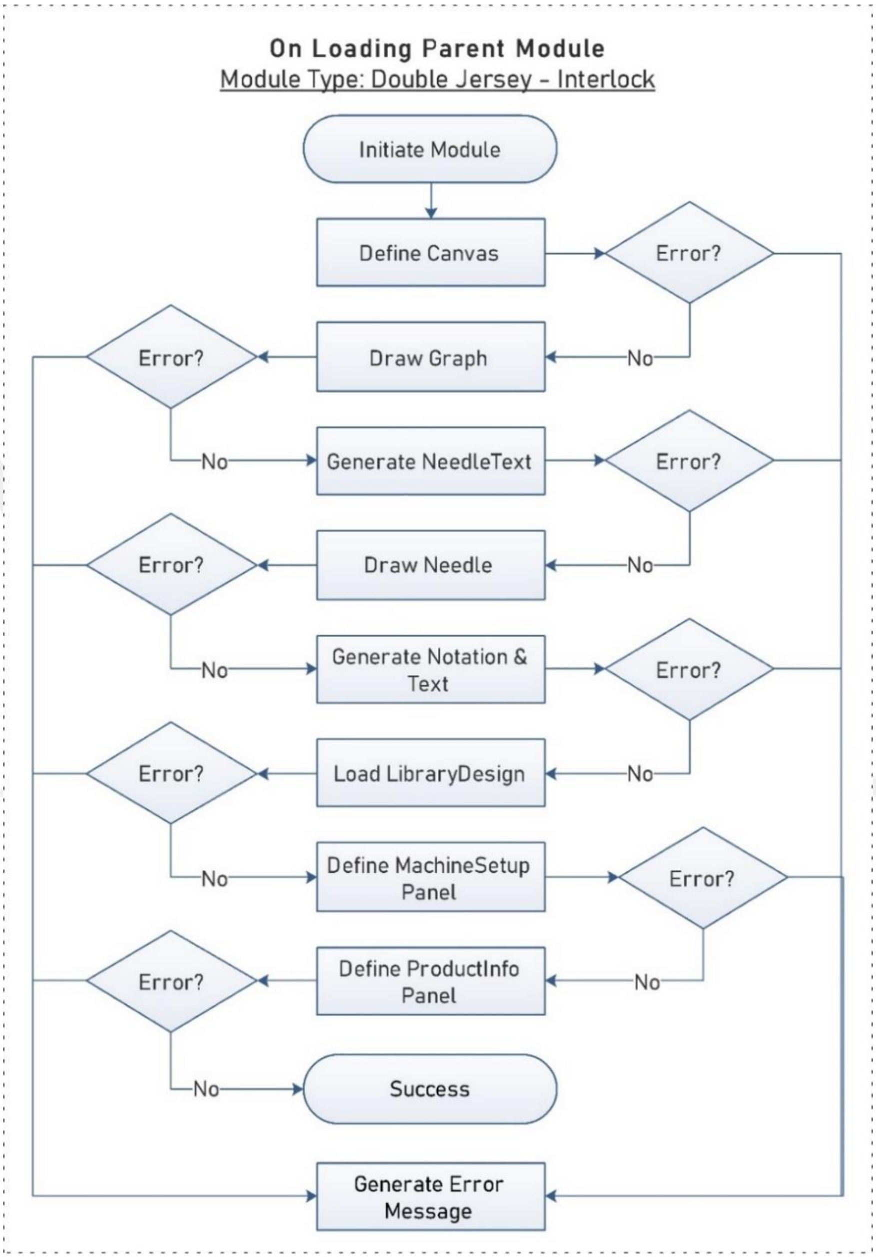


Figure appx-1.37. Composition of Interlock module

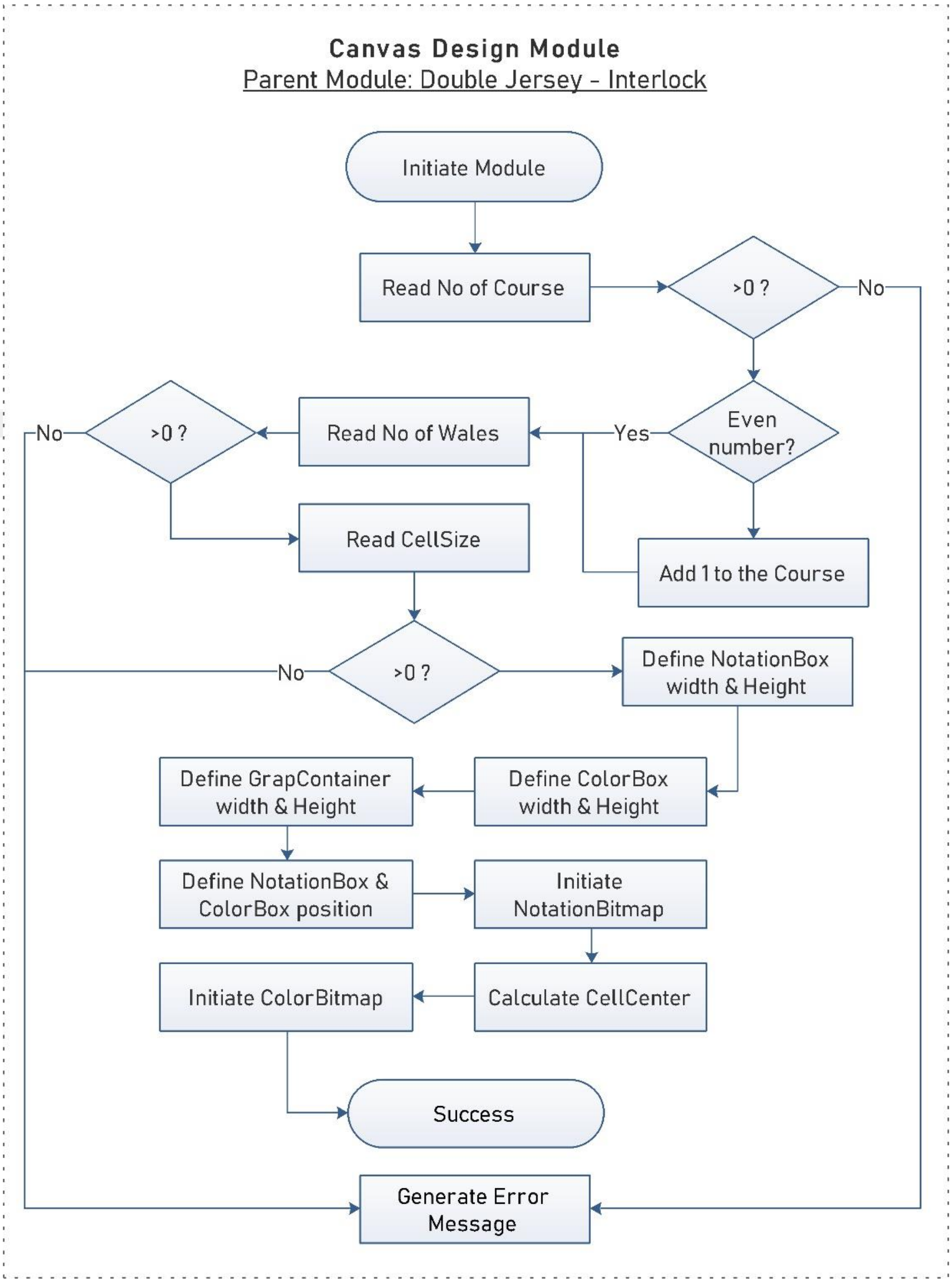


Figure appx-1.38. Algorithm for canvas design for interlock

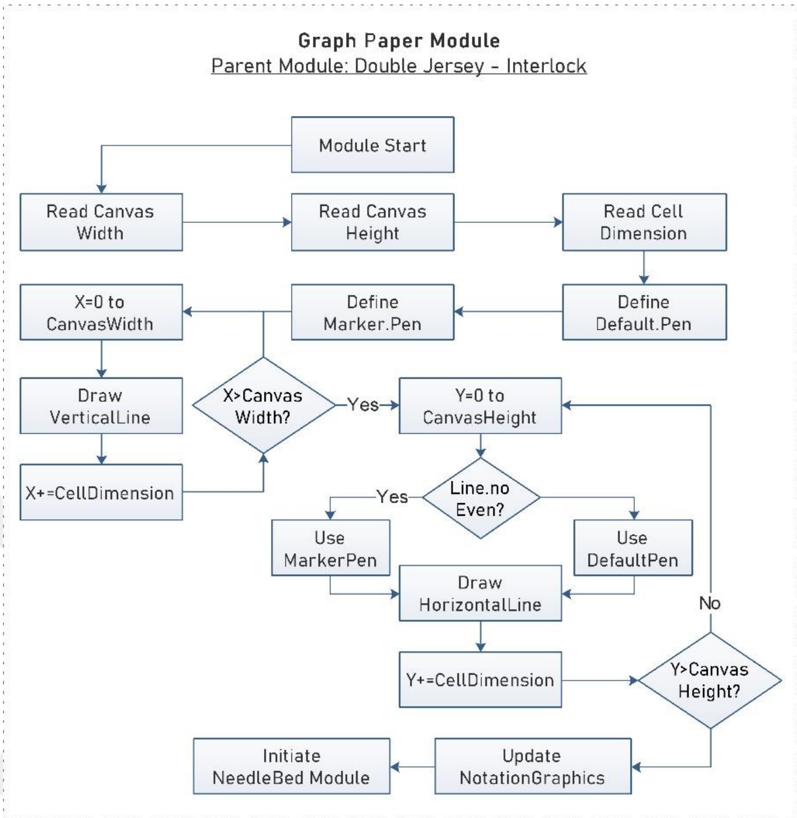


Figure appx-1.39. Graph module for interlock

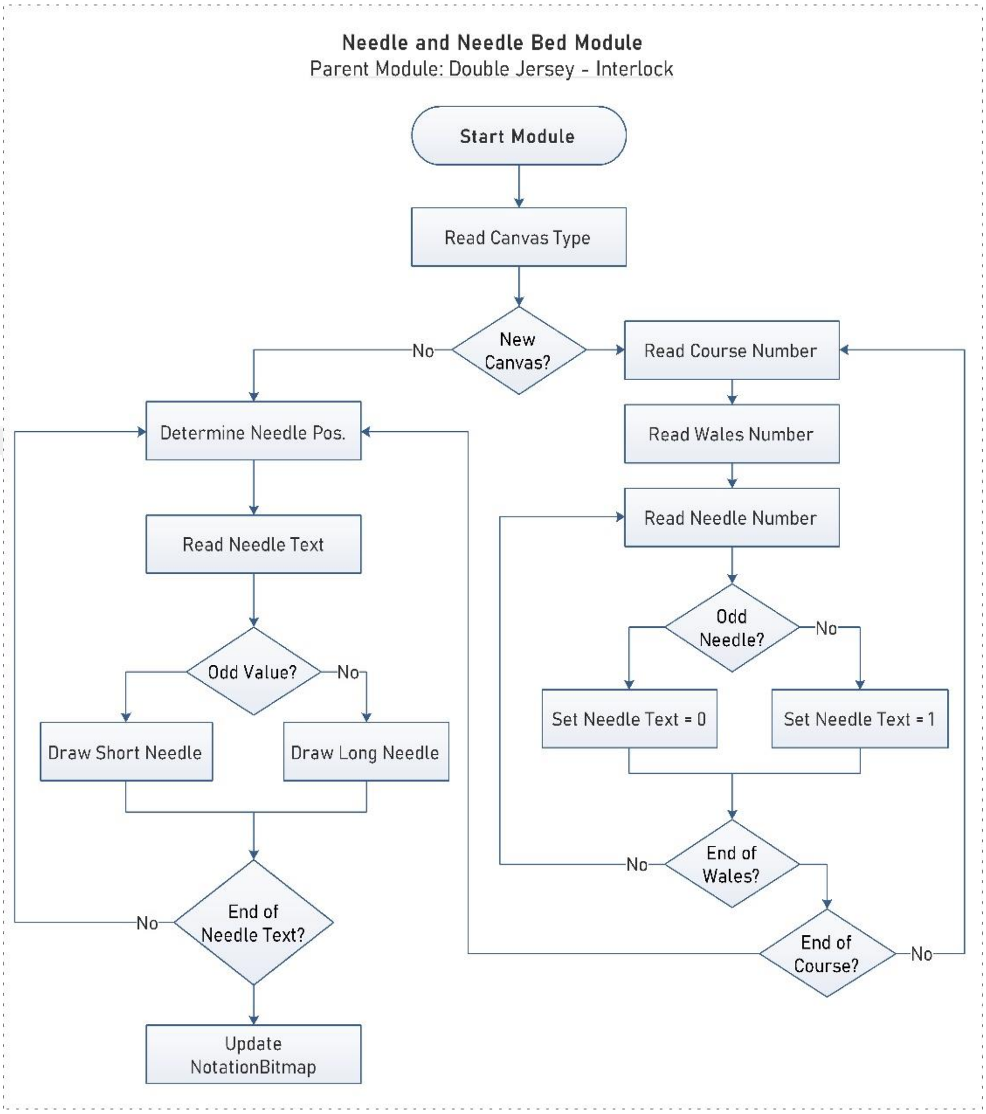


Figure appx-1.40. Algorithm for needle bed module in interlock

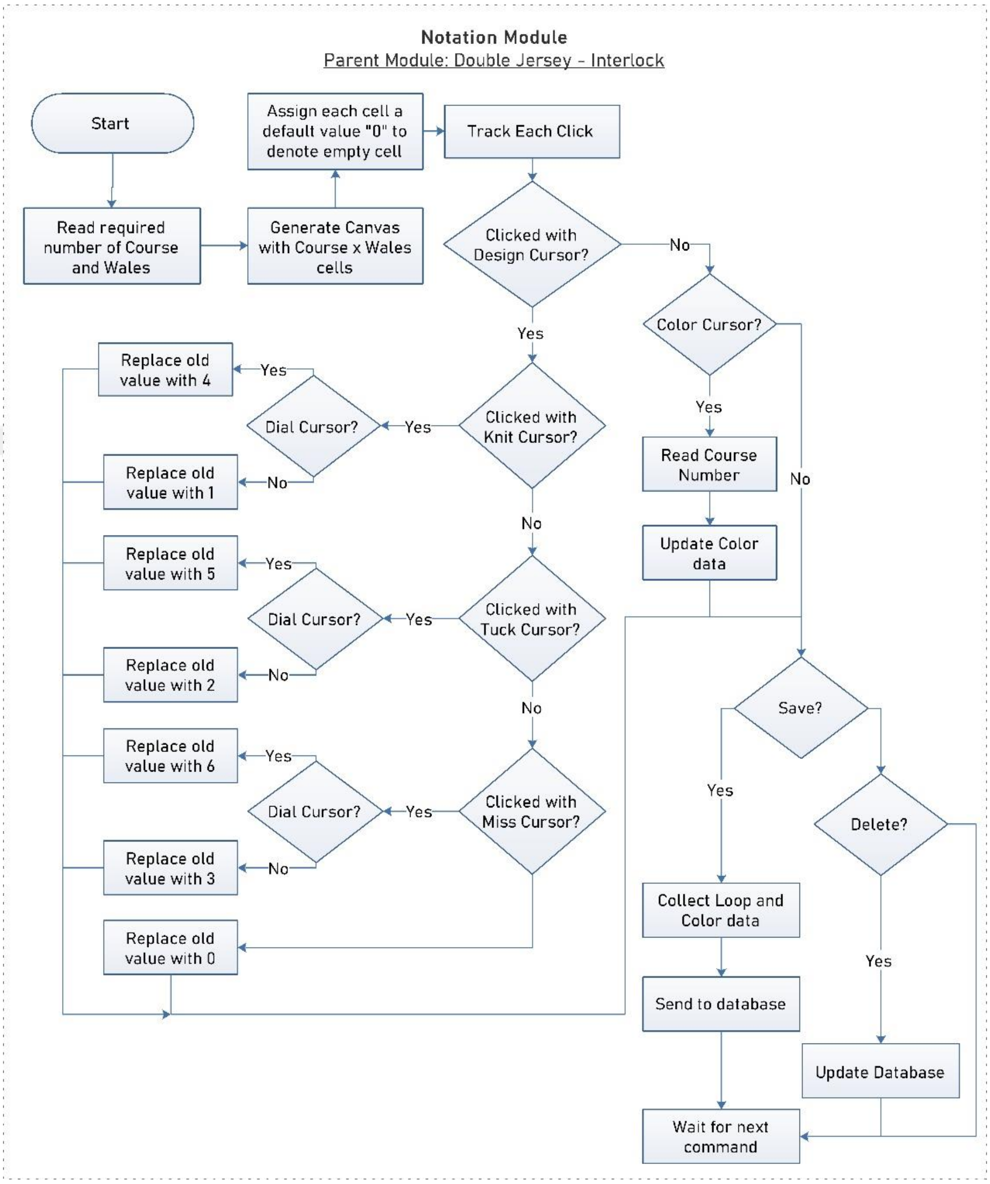


Figure appx-1.41. Notation module in interlock

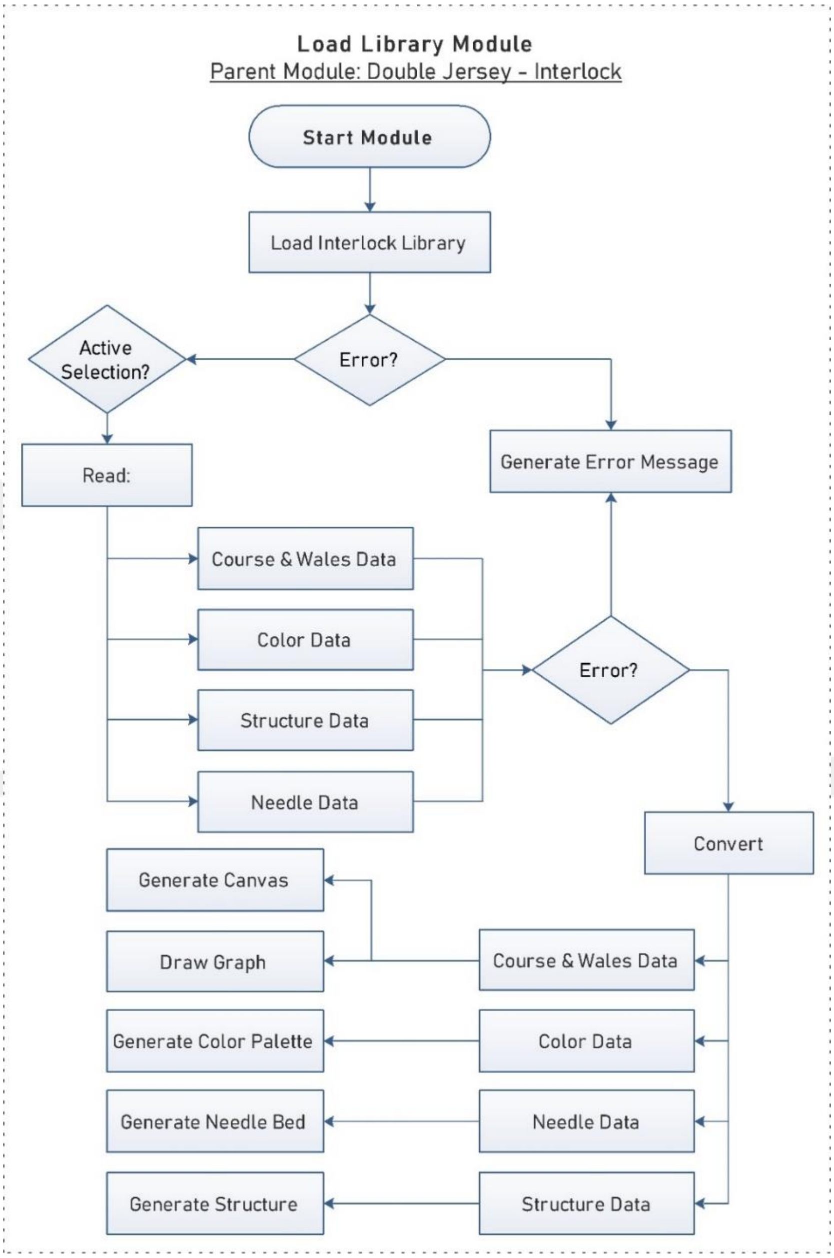


Figure appx-1.42. Library module for reloading interlock structure

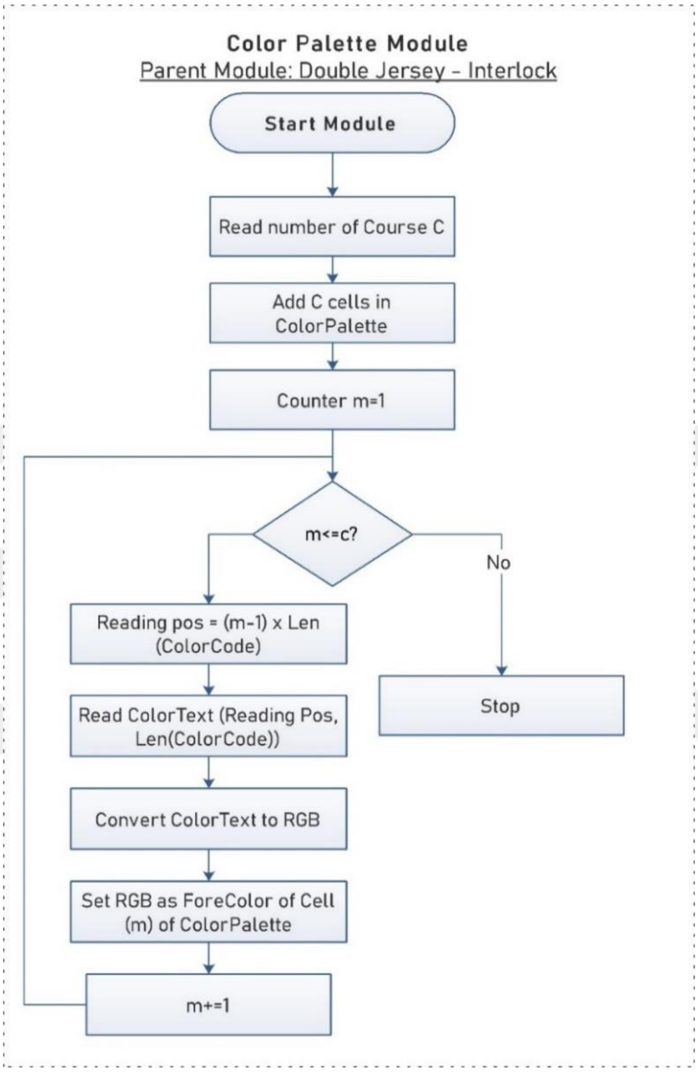


Figure appx-1.43. Color palette module in interlock

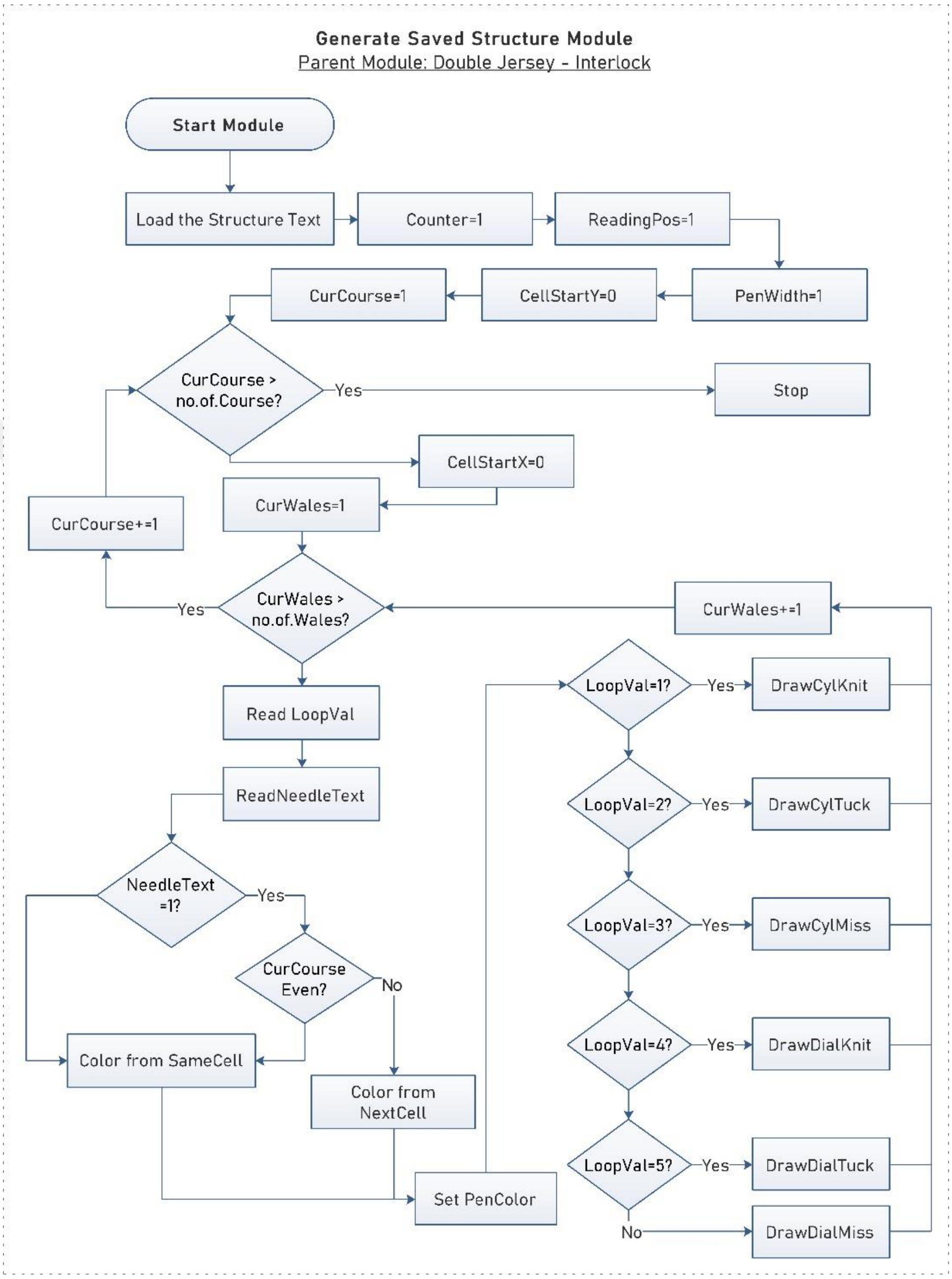


Figure appx-1.44. Module for generating structure from interlock library

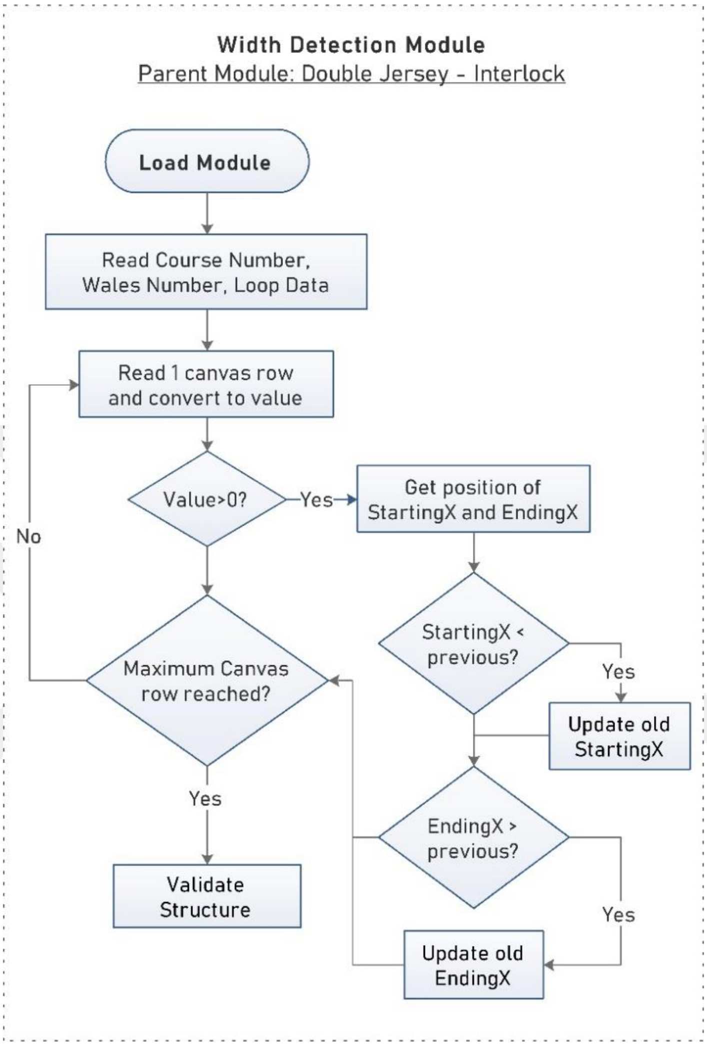


Figure appx-1.45. Width calculation module in interlock

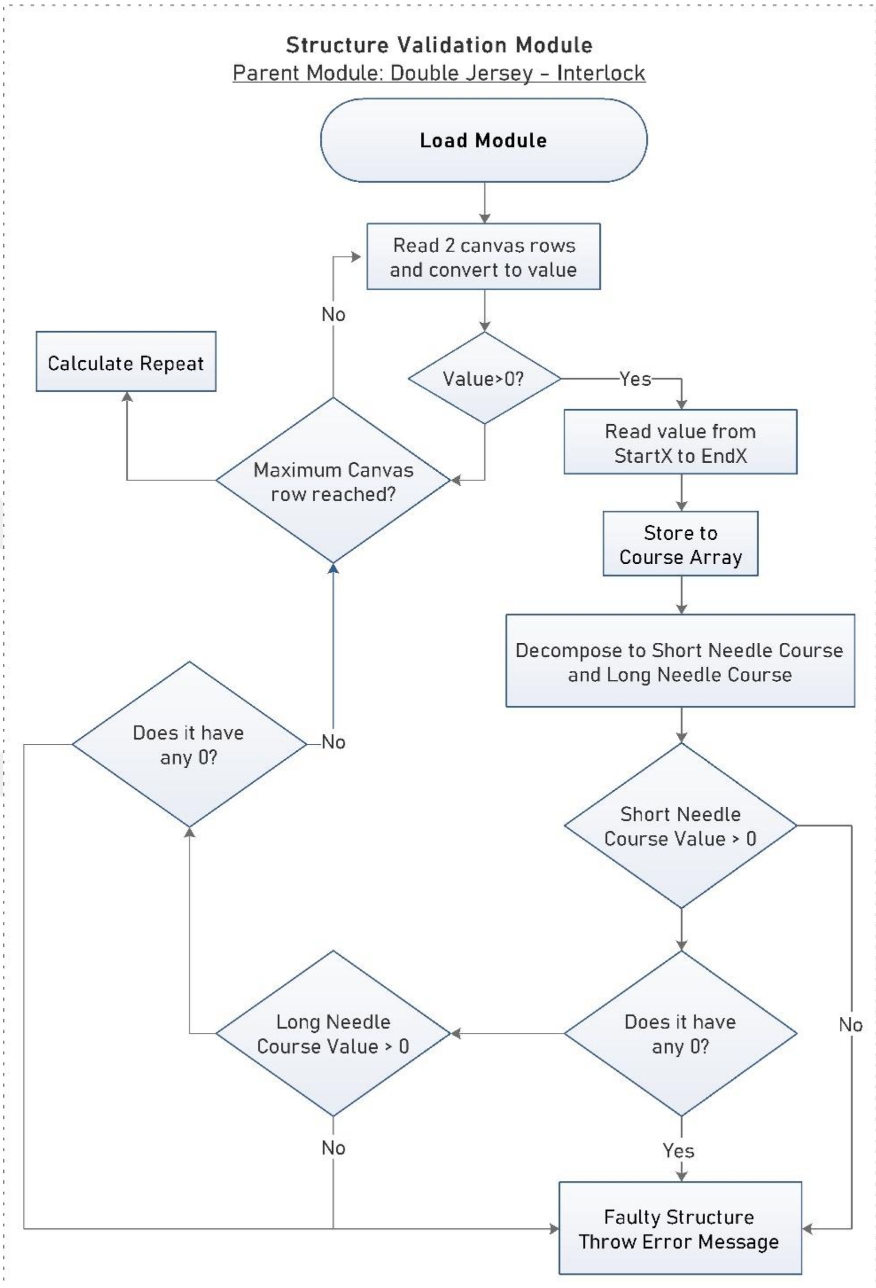


Figure appx-1.46. Structure validation in interlock

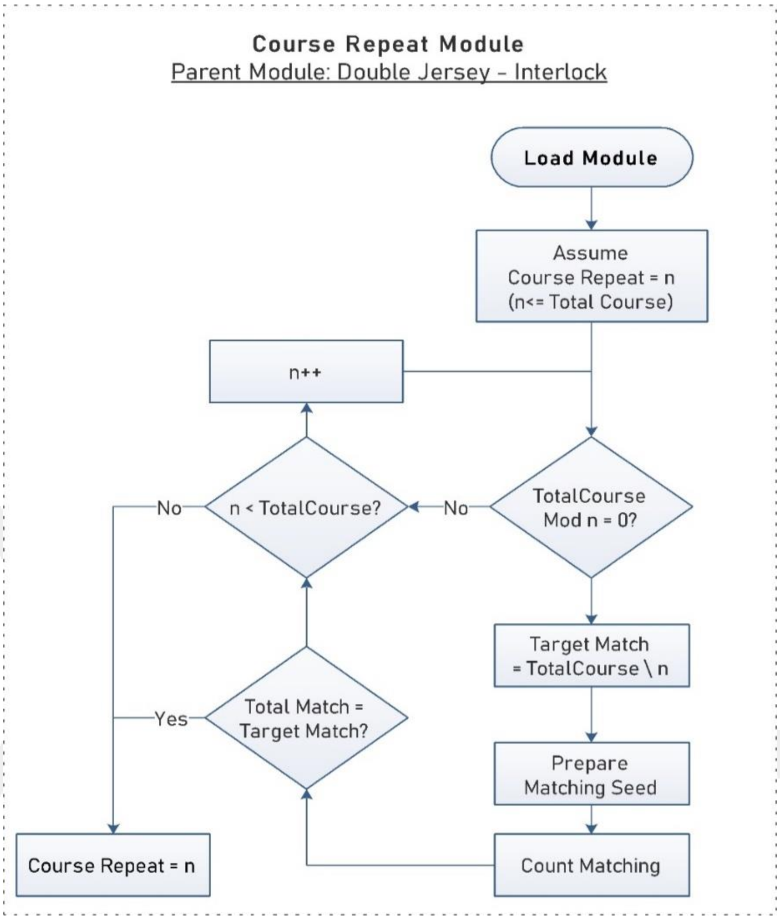


Figure appx-1.47. Course repeat identification module in interlock

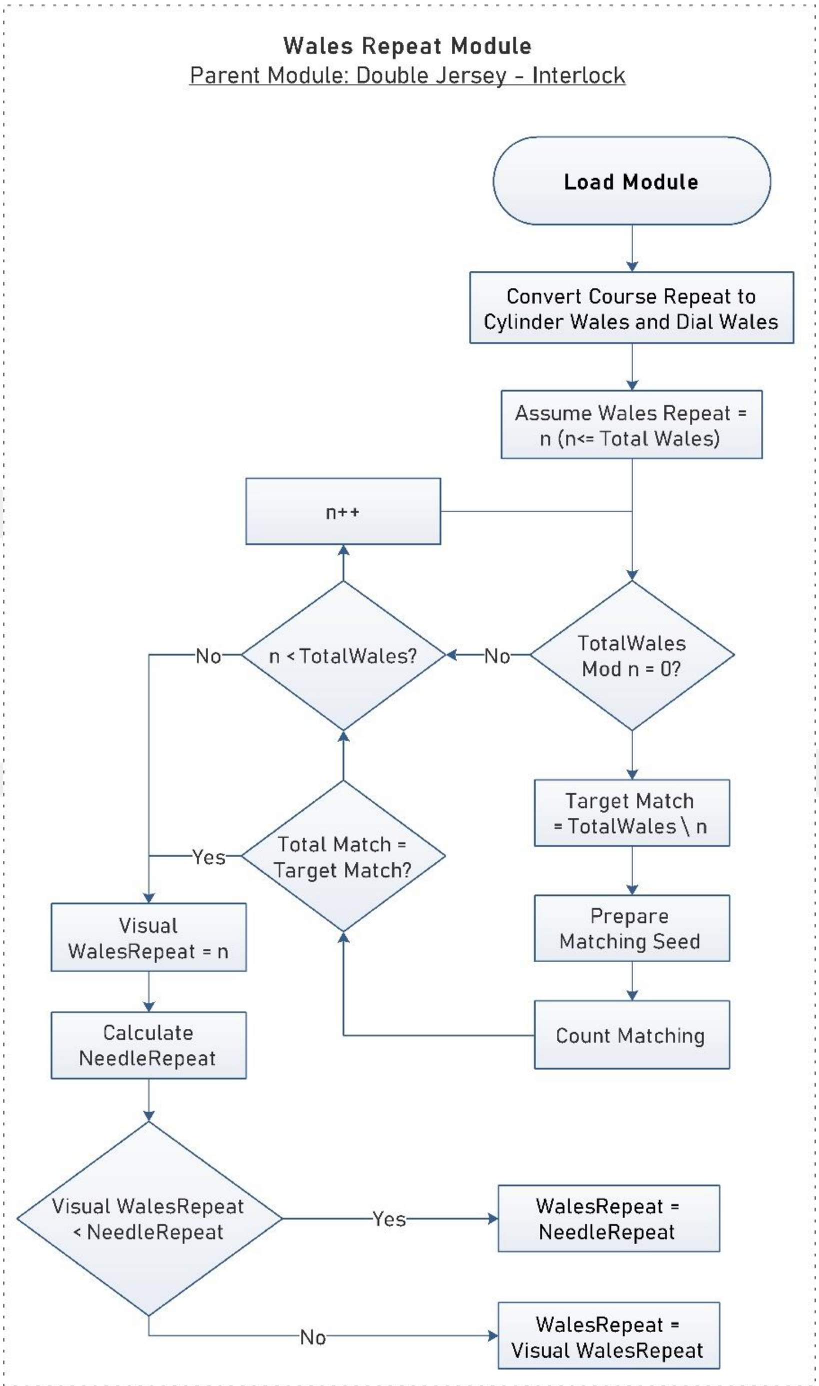


Figure appx-1.48. Wales repeat identification module in interlock

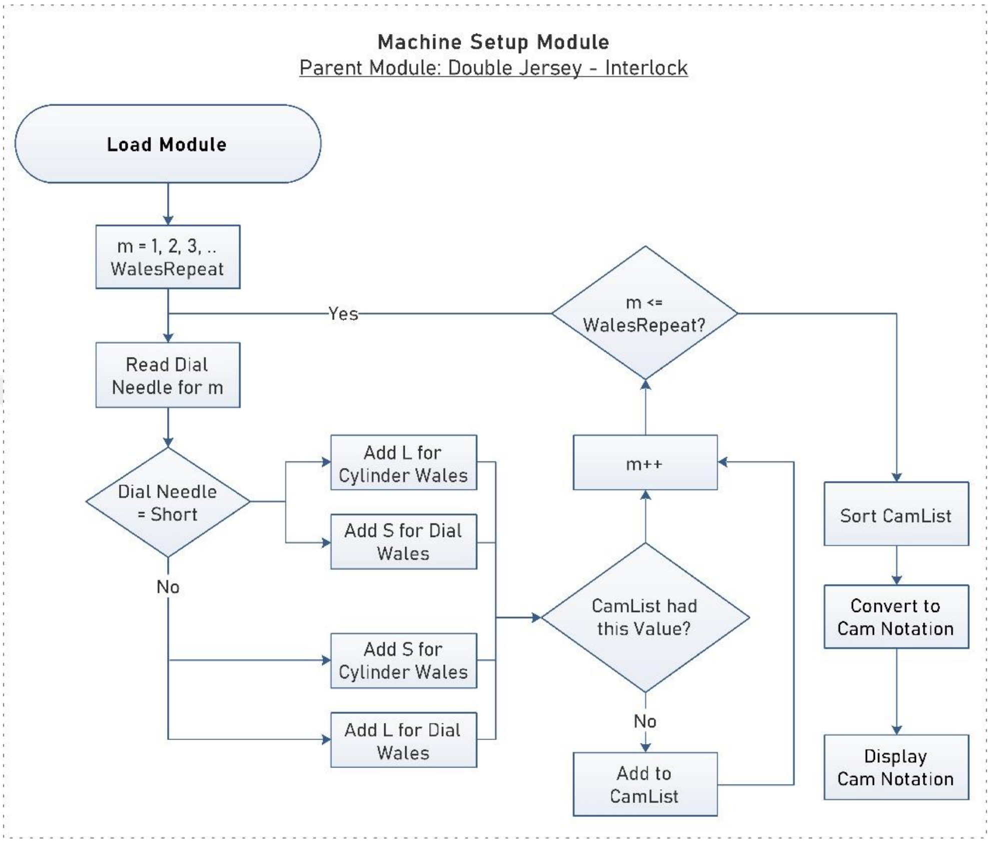


Figure appx-1.49. The machine setup module in interlock

APPENDIX-2: Validation of Calculation Module

Table appx-2.1. Production per hour in kg: Single Jersey

Sample	Machine Speed (RPM)	Active Feeders	Efficiency (%)	Machine Diameter (inch)	Machine Gauge (npi)	Stitch Length (cm/50 stitch)	Yarn Count (Ne)	Actual Production (kg/hr)	Software Predicted (kg/hr)	Prediction Accuracy (%)
1	26	90	80	30	28	14.50	30	17.30	16.92	97.81
2	26	96	80	32	28	13.50	30	18.40	17.92	97.40
3	26	102	80	34	28	14.00	30	21.14	20.98	99.25
4	26	90	80	30	22	16.00	20	23.00	22.00	95.66
5	26	96	80	32	22	15.50	20	25.38	24.25	95.55
6	26	102	80	34	22	17.00	20	31.18	30.02	96.28

Table appx-2.2. Production per hour in kg: Rib

Sample	Machine Speed (RPM)	Active Feeders	Efficiency (%)	Machine Diameter (inch)	Machine Gauge (npi)	Stitch Length (cm/50 stitch)	Yarn Count (Ne)	Actual Production (kg/hr)	Software Predicted (kg/hr)	Prediction Accuracy (%)
1	20	60	80	34	20	28.00	30	14.20	13.56	95.50
2	20	60	80	34	18	27.00	30	12.30	11.77	95.70
3	24	54	80	30	18	29.50	24	15.39	15.32	99.55
4	18	68	80	38	18	31.50	20	24.34	23.48	96.47

Table appx-2.3. Production per hour in kg: Interlock

Sample	Machine Speed (RPM)	Active Feeders	Efficiency (%)	Machine Diameter (inch)	Machine Gauge (npi)	Stitch Length (cm/50 stitch)	Yarn Count (Ne)	Actual Production (kg/hr)	Software Predicted (kg/hr)	Prediction Accuracy (%)
1	22	96	80	30	24	16.00	30	15.07	14.44	95.82
2	22	96	80	30	28	15.00	40	12.45	11.85	95.19
3	20	102	80	34	24	17.00	30	17.53	16.80	95.84
4	20	102	80	34	28	15.50	40	14.00	13.40	95.72

Table appx-2.4. GSM prediction: Single Jersey

Sample	Course per cm	Wales per cm	Stitch Length (cm/50 stitch)	Yarn Count (Ne)	Actual GSM(g/m²)	Software Predicted GSM(g/m²)	Prediction Accuracy (%)
1	20.86	15.35	13.85	30	146.00	174.58	80.42
2	16.14	12.20	17.00	20	188.00	197.67	94.86
3	15.74	12.59	17.00	20	182.00	198.93	90.70

Table appx-2.5. GSM prediction: Rib

Sample	Course per cm	Wales per cm	Stitch Length (cm/50 stitch)	Yarn Count (Ne)	Actual GSM(g/m²)	Software Predicted GSM(g/m²)	Prediction Accuracy (%)
1	17.71	9.84	27.00	30	175.00	185.23	94.15
2	18.89	10.23	26.00	30	202.00	197.79	97.92

Table appx-2.6. GSM prediction: Interlock

Sample	Course per cm	Wales per cm	Stitch Length (cm/50 stitch)	Yarn Count (Ne)	Actual GSM(g/m²)	Software Predicted GSM(g/m²)	Prediction Accuracy (%)
1	19.29	16.14	13.50	40	210.00	248.19	81.81
2	16.14	13.38	16.50	20	346.00	420.82	78.38

Table appx-2.7. Prediction of elastane content in the fabric

Sample	Length of Measured Yarn (cm)	Count of Yarn (Ne)	Elastane with no Tension (cm)	Count of Elastane (Denier)	Feed Ratio	Actual Elastane Content Found (%)	Software Predicted Elastane Content (%)	Prediction Accuracy (%)
1	31	30.00	10.50	20.00	1.00	3.67	3.68	99.63
2	31	30.00	11.00	30.00	1.00	5.64	5.67	99.48
3	27	40.00	10.50	20.00	1.00	5.52	5.53	99.80
4	33	24.00	12.00	40.00	1.00	6.11	6.16	99.10

APPENDIX-3: Validation of Simulation Module

Fabric Specification

Name	Manu	Needle Arrangement	/1,2,3,2/
Type	Jersey Lacoste	Cam Arrangement	
Color			
Yarn Count	30/1, 24/1		
Machine Dia	32		
Machine Gauge	28		
Stitch Length	2.90 mm		

Cam Arrangement:

T	K	K	K		K	K	
K	K	T	K		K	K	
T	K	K	K		K	K	
3					18		

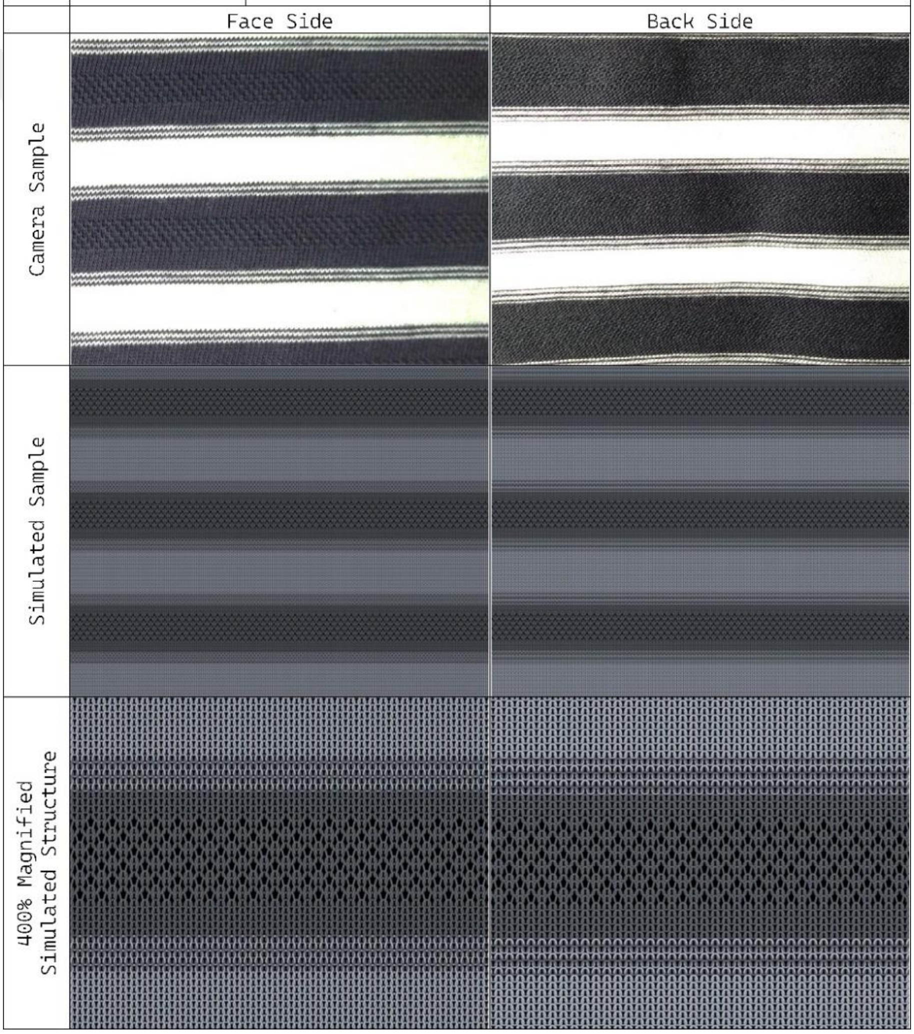


Figure appx-3.1. Single Jersey (Manu) – Actual fabric vs simulated view

Fabric Specification			
Name	Espinado Lacoste	Needle Arrangement	/1,2,3,2/
Type	Single Jersey	Cam Arrangement	
Color	Indigo		
Yarn Count	24/1 Ne		
Machine Dia	26		
Machine Gauge	28		
Stitch Length	2.84 mm		

Cam Arrangement:

K	T	K	K				
K	K	K	T				
K	T	K	K				
K	K	K	T				

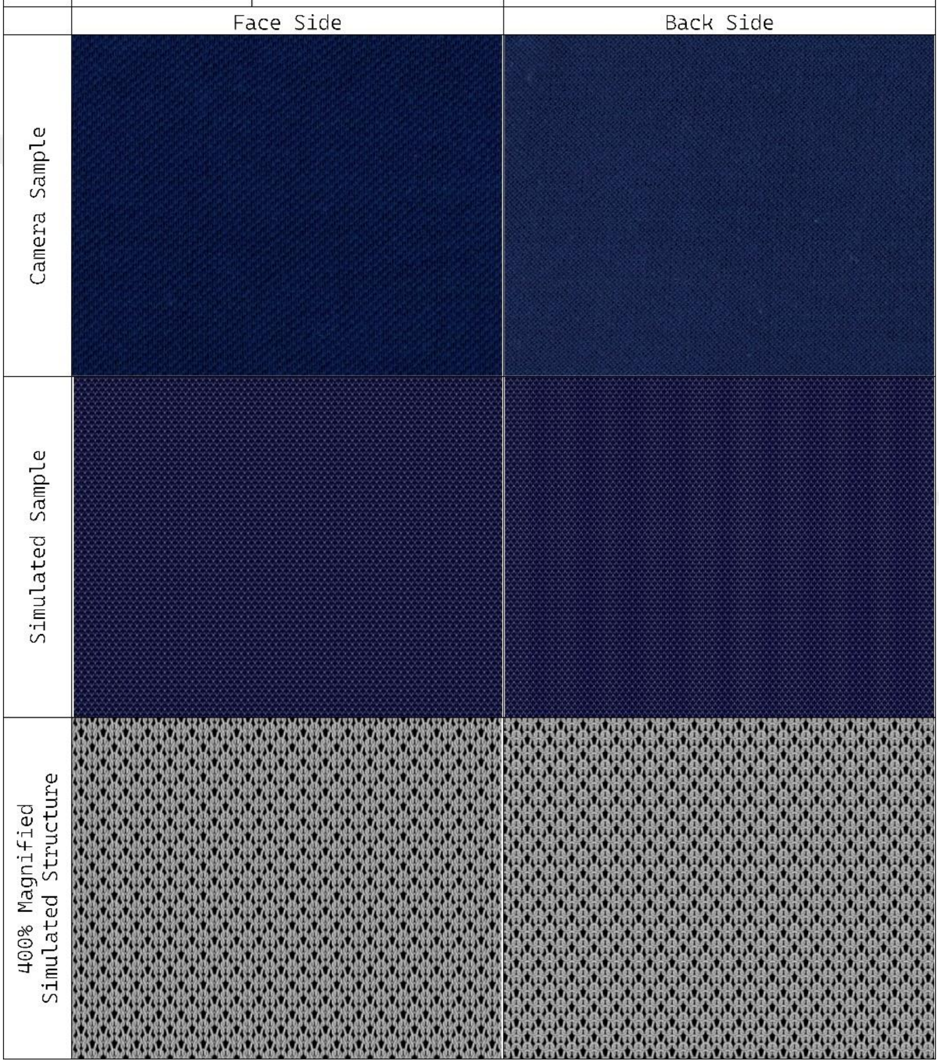


Figure appx-3.2. Single Jersey (Esp Lacoste) – Actual fabric vs simulated view

Fabric Specification				
Name	Kaskorse Heavy	Needle	/1,2,0,2,1,0//1,2,0,2,1,0
Type	Double Jersey	Cam Arrangement	
Color	Indigo		
Yarn Count	30/1		
Machine Dia	30		
Machine Gauge	28		
Stitch Length	- mm		

Cam Arrangement:

K	K						
K	K						
K	K						
K	K						

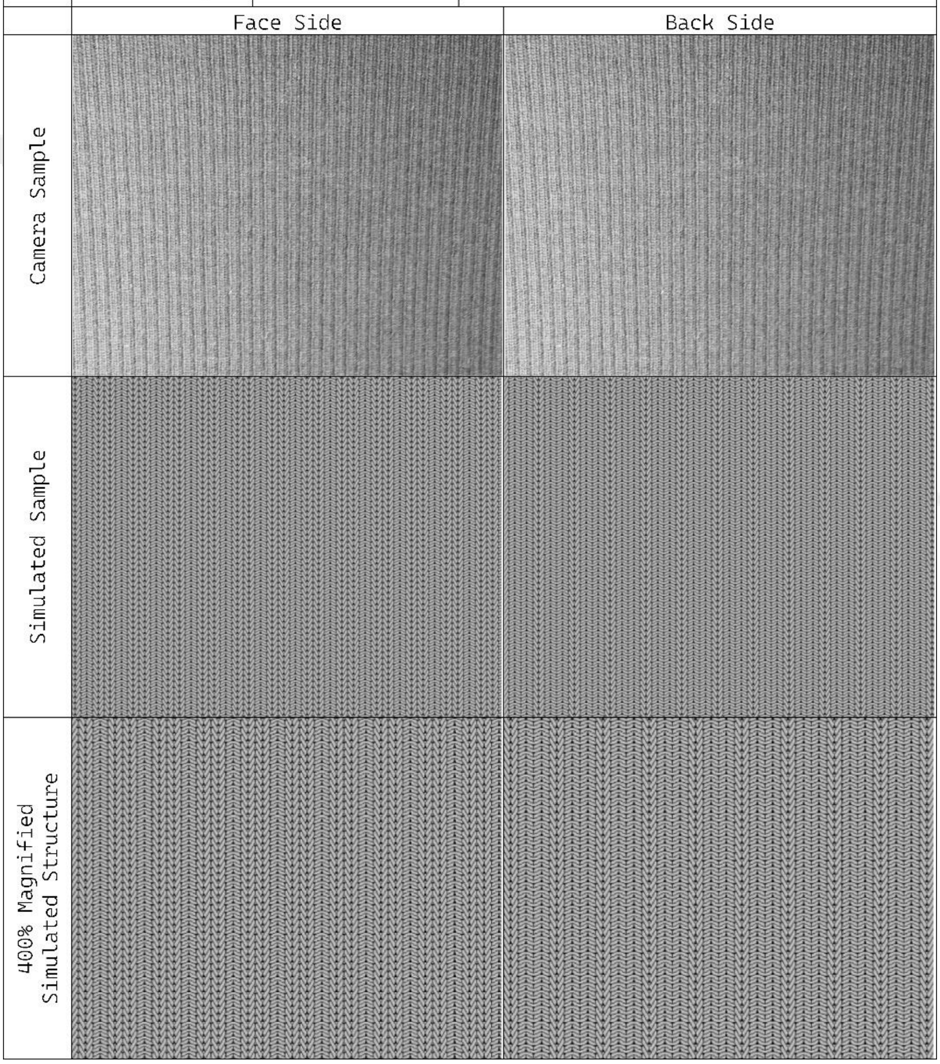


Figure appx-3.3. Double Jersey (K. Heavy) – Actual fabric vs simulated view

Fabric Specification				
Name	Wave	Needle Arrangement	/1,2,3,2/
Type	Single Jersey	Cam Arrangement	
Color	Giner		
Yarn Count	16/1		
Machine Dia	26		
Machine Gauge	22		
Stitch Length	3.1 mm		

Face Side | Back Side

Camera Sample

Simulated Sample

400% Magnified Simulated Structure

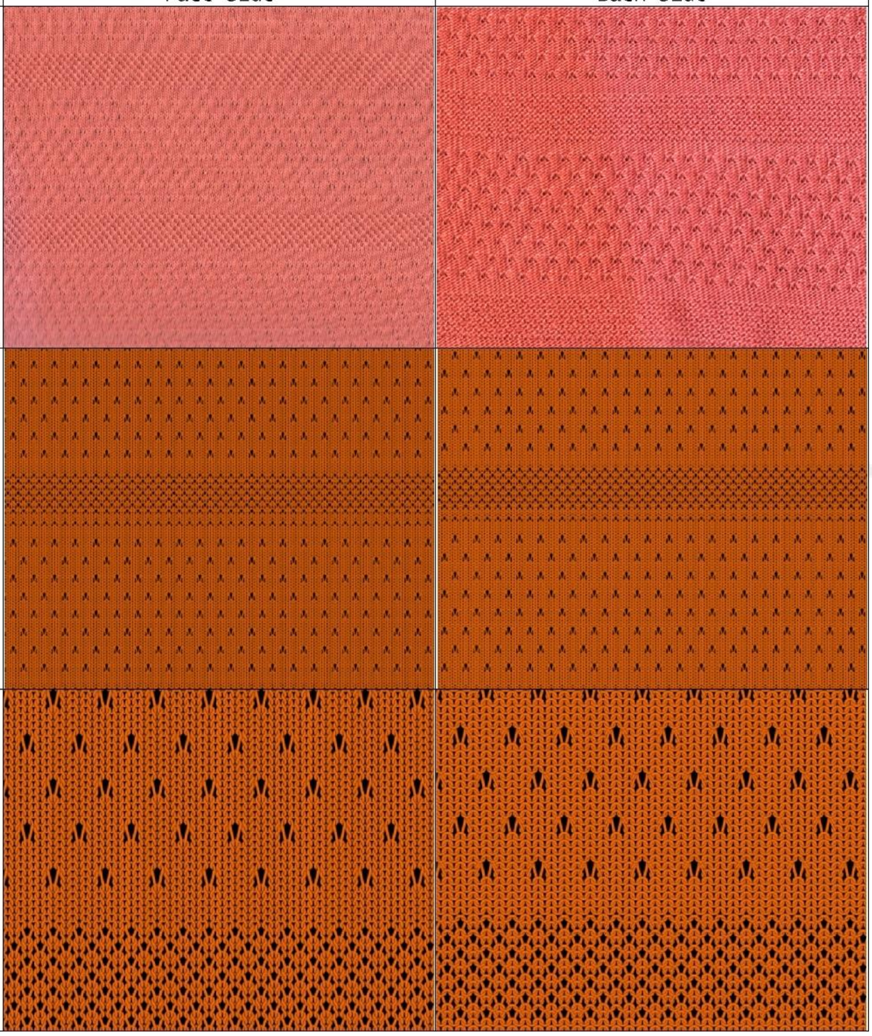


Figure appx-3.4. Single Jersey (Wave) – Actual fabric vs simulated view

Fabric Specification		
Name	Lapis	Needle Arrangement: /1,2,3,2/
Type	Jersey	Cam Arrangement
Color		
Yarn Count	30/1	
Machine Dia	32	
Machine Gauge	28	
Stitch Length	2.84 mm	

Cam Arrangement:

K	K	K	K				
K	K	K	K				
K	K	K	K				

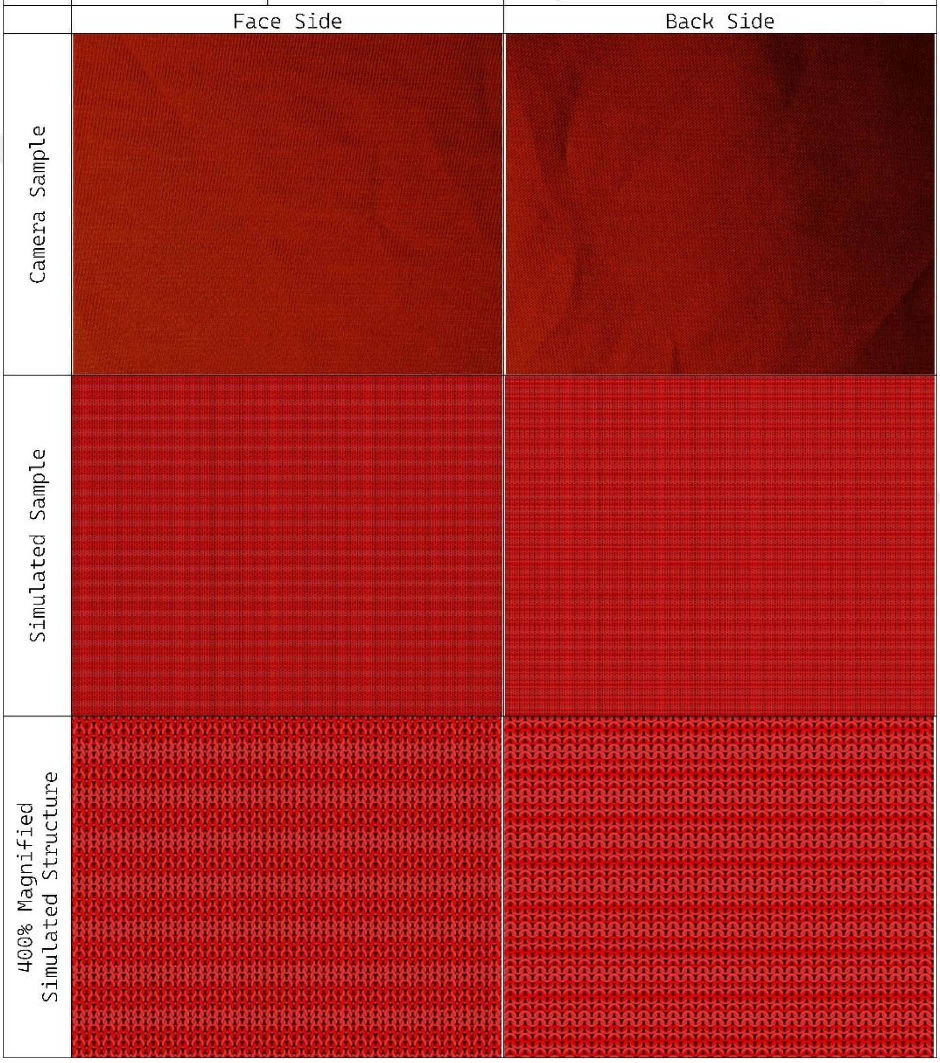


Figure appx-3.5. Single Jersey (Lapis) – Actual fabric vs simulated view

Fabric Specification				
Name	Orion Flam Stripe	Needle Arrangement		
Type	Single Jersey	Cam Arrangement		
Color	Stripe			
Yarn Count	20/1			
Machine Dia	32			
Machine Gauge	22			
Stitch Length	3.64 mm			

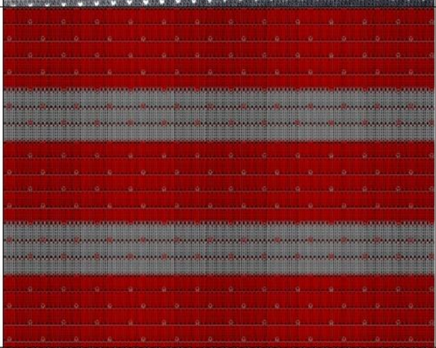
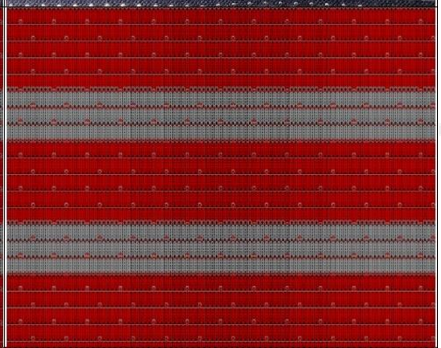
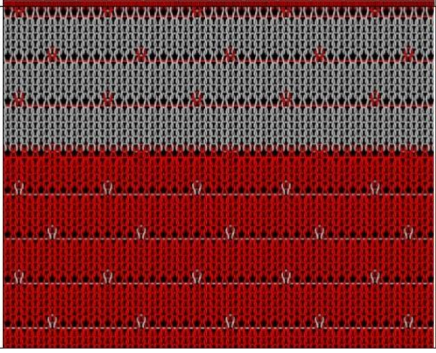
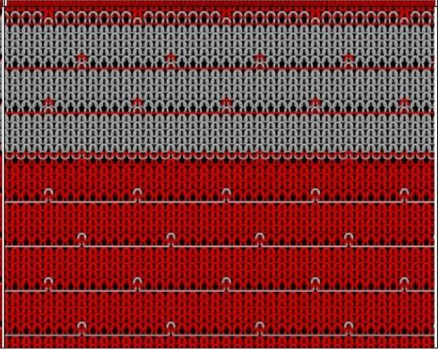
	Face Side	Back Side
Camera Sample		
Simulated Sample		
400% Magnified Simulated Structure		

Figure appx-3.6. Single Jersey (O. F. Stripe) – Actual fabric vs simulated view

Fabric Specification			
Name	Supreme Pike	Needle Arrangement	/1,2,3,2/
Type	Jersey & Lacoste	Cam Arrangement	
Color			
Yarn Count	30/1 Ne		
Machine Dia	26		
Machine Gauge	28		
Stitch Length	2.80 mm		

Cam Arrangement:

K	K	K	T	K	K		
K	K	K	K	K	T		
K	K	K	T	K	K		
K	K	K	K	K	T		

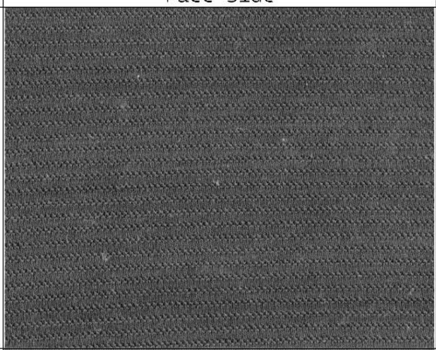
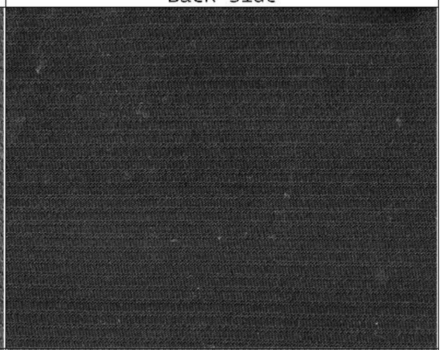
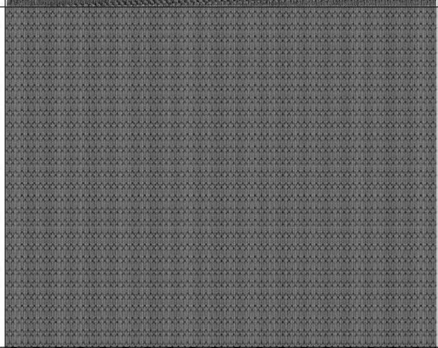
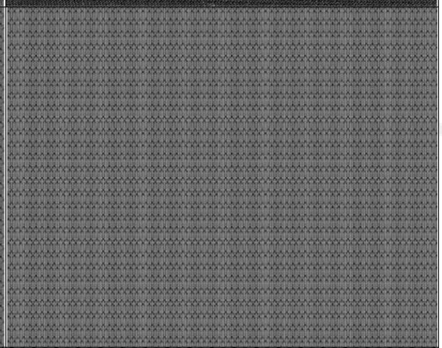
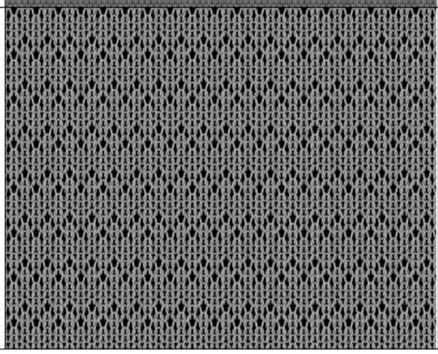
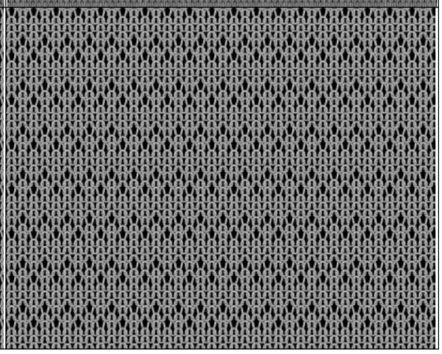
	Face Side	Back Side
Camera Sample		
Simulated Sample		
400% Magnified Simulated Structure		

Figure appx-3.7. Single Jersey (S. Pike) – Actual fabric vs simulated view

Fabric Specification

Name	Loki Flam Stripe	Needle Arrangement	/1,2,3,2/
Type	Jersey	Cam Arrangement	
Color	Combo		
Yarn Count	24/1 Ne Slub		
Machine Dia	32		
Machine Gauge	22		
Stitch Length	3.36 mm		

Cam Arrangement:

K	K	K	K				
K	K	K	K				
K	K	K	K				
K	K	K	K				

Face Side | Back Side

Camera Sample

Simulated Sample

400% Magnified Simulated Structure

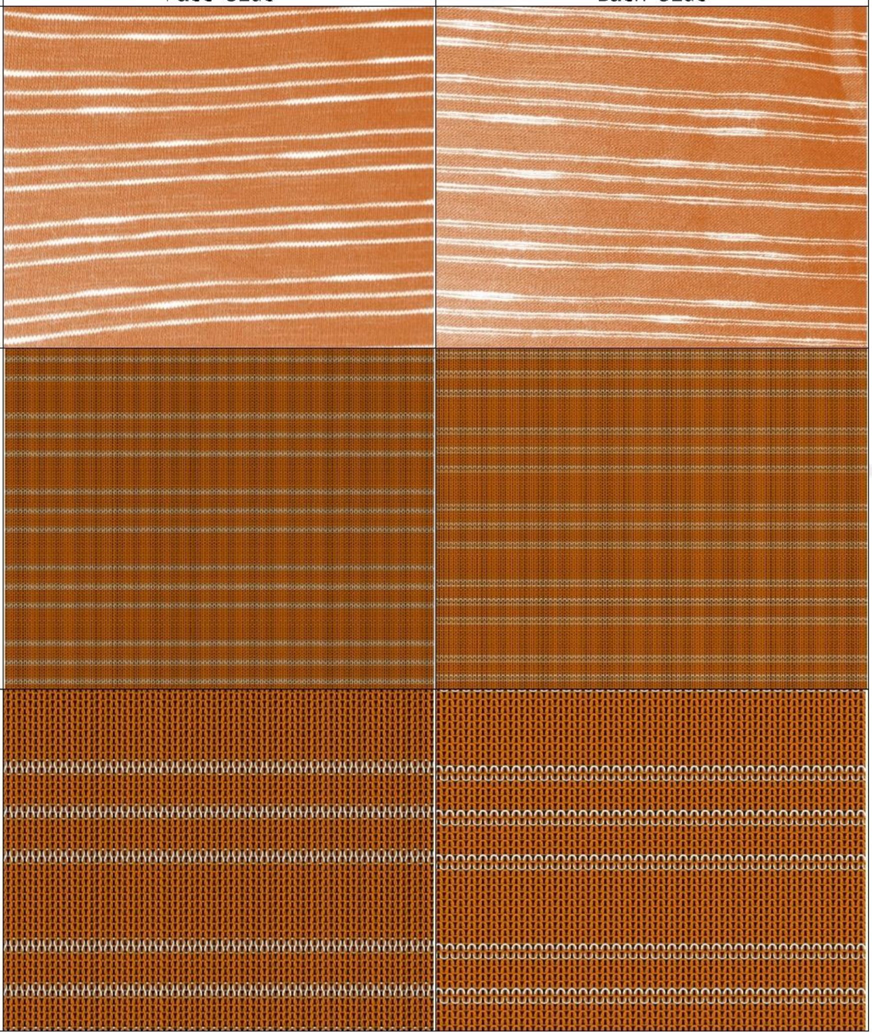


Figure appx-3.8. Single Jersey (L. F. Stripe) – Actual fabric vs simulated view

Fabric Specification			
Name	Pike	Needle Arrangement	/1,2,3,2/
Type	Lacoste	Cam Arrangement	
Color	Indigo		
Yarn Count	30/1 Ne Slub		
Machine Dia	26		
Machine Gauge	28		
Stitch Length	2.76 mm		

Cam Arrangement:

K	T	K	K				
K	K	K	T				
K	T	K	K				
K	T	K	K				

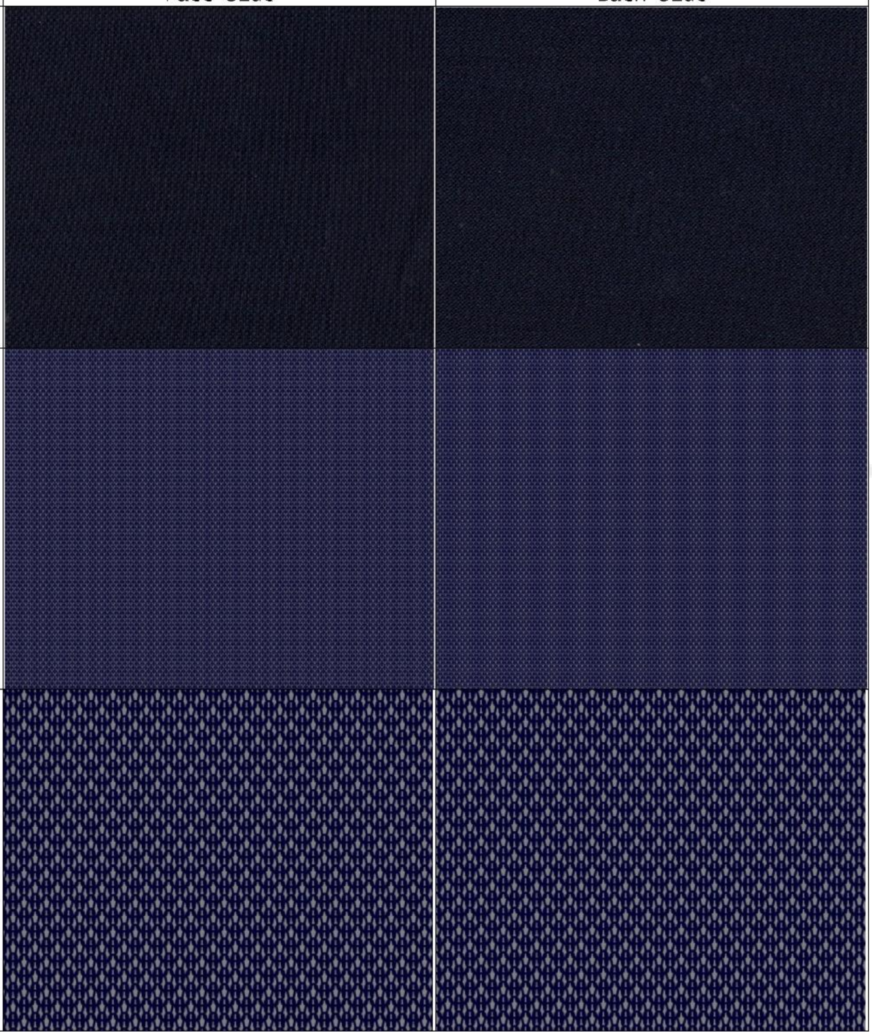


Figure appx-3.9. Single Jersey (P. Lacoste) – Actual fabric vs simulated view