Presentation to the Society for Underwater Technology.
This talk to the Perth branch of the Society for Underwater Technology covers some of the history of umbilicals, their present usage in the context of subsea to beach production systems, and peers into the future.

The drivers for subsea to beach umbilical systems are discussed:

- technological
- economic
- environmental
Umbilicals could never be described as "sexy" - not that they turn me on!
But they do fascinate me, and I hope that I can share some of that excitement with you, as I attempt to dispel the boring image that they have acquired.
Umbilicals should never be regarded as an end in themselves. They are used strictly to provide services from surface to subsea:
- electrical power
- signals
- hydraulic pressure
I will discuss the development of umbilical systems on a decade by decade basis.

**The Sixties**

The first subsea well was installed in 1961, by Shell in the Gulf of Mexico, in a water depth of fifty feet (16 m).

The umbilicals supporting these early wells were direct hydraulic, with a large number of hydraulic cores (one for each tree valve).

Interestingly (to me anyway), two other inventions were made at around the same time which were to profoundly influence the nature of umbilicals:

- Jack Kilby invented the integrated circuit in 1958. He made the discovery over a holiday period when he was compelled to work because he had used up all his holiday allowance.
- Ted Maiman built the first laser in 1960. He used high purity ruby rods from Union Carbide, a material that other industry gurus had dismissed as being unsuitable for lasing.
Development of Umbilicals

Direct hydraulic
- large umbilicals, one hose per valve

Multiplexed electrohydraulic
- smaller umbilicals

The Seventies
Multiplexed electrohydraulic control systems were introduced, permitting much smaller umbilicals.
This innovation was based on application of technology from two different areas:
  - Use of directional control valves from the avionics industry
  - Use of electronic control circuits using transistors or newly developed integrated circuits

The Eighties
1983 saw a damning report from the Engineering Research Council in the UK.
Problems and failures were occurring in the electrical and hydraulic cores and connectors of umbilical systems, with an overall level of reliability that could only be described as poor.
  - Leaks from connections and hydraulic fittings
  - Permeation from methanol hoses into other hydraulic cores and cables
  - Hose collapse
  - Water ingress into electrical cables and connectors
Development of Umbilicals

Direct hydraulic
- large umbilicals, one hose per valve

Multiplexed electrohydraulic
- smaller umbilicals

Steel tubes
- high reliability

Fibre optics
- long distance

The Nineties
This decade saw the introduction of steel tubes and fibre optics.
The steel tubes eliminated the failure modes of thermoplastic hoses at a stroke (leaks, permeation, and hose collapse).
Unfortunately some early teething problems were experienced. One failure mode affecting superduplex steel tube was experienced by BP, who went public with their remediation program, greatly benefiting the rest of the industry.
Fibre optics gave umbilicals the potential for greatly increased distances for signal transmission, with enormously increased bandwidth, together with immunity to electrical interference.

The Noughties (?!)
In this decade, the electrical problems that have plagued umbilicals for so long will be finally overcome.
The first set of subsea developments shown above are stepouts of up to 67 km. These use comms on power with single phase power distribution at 600 Vac.

The East Spar buoy sits within these systems, begging the question of why a buoy was chosen. The answer to this question is given in detail in the Subsea Technology module of the Master of Oil and Gas Engineering course at the University of Western Australia.

Burullus Simian Sienna at 77 km with expansion up to 112 km uses separate power and comms to avoid noise and signal degradation from the power line. The supply voltage is also increased to 1000 Vac to cope with the longer stepout. The ill-fated Corrib project in Ireland had a similar stepout and used similar technology, but foundered when government approvals could not be obtained. Unfortunately, by then, the equipment had been ordered and built. Now there’s a lesson for us! Gorgon has a similar stepout to these fields.

Mensa was a record-breaking project because of stepout and water depth. It had separate power and comms, and used 3-phase electrical power at 720 Vac. Three phase power gives more efficient transmission than two phase, as three cores can more effectively fill a round cable than two cores.

The next phase of subsea-to-beach projects in the Norwegian sector presents a quantum leap in distance and technology. Fibre-optics are used for signal transmission, and electrical power transmission is by high voltage ac (3kV ac).
Most of the salient features of this graph have already been discussed, but some points are worthy of notice.

There is an ongoing crop of short-distance subsea to beach projects (e.g. Patricia Baleen, BHPBP Minerva, and ONGC G-1, India’s first subsea-to-beach development).

One short stepout project utilised a control buoy. Petrobras used the 4-ALS-39 buoy at a distance of 25km to control a single well.

Some extreme stepout projects are already on the radar. BHPBP Scarborough at 280km and the gigantic Shtokman field in the Russian sector of the Arctic with a stepout of 500 km are already being considered.

We should note with pride that two very significant projects (the East Spar Buoy and BHPBP Scarborough) are in Australian waters. Never imagine for a moment that this area is a sleepy backwater. And I think that BHPBP deserve praise for their boldness in even thinking of developing the remote Scarborough field. The distance from the Scarborough field to the Pilbara LNG plant at Onslow is 280 km. Yes, 280 km.
Electrical Power Transmission

Trend to 3 phase power and DC
Today’s technology can supply (at 36kV AC)
• 30 MVA up to 50 km
• 20 MVA up to 250 km
Future requirements can be met by increasing AC voltages and by DC transmission

Electrical power transmission presents no difficulties for umbilical systems.
Virtually any necessary stepout or power demand can be met with present equipment.
There is a trend towards DC transmission of electrical power. This is more efficient as AC dielectric losses in the cables are avoided. The equipment vendors are starting to manufacture and promote DC control systems.
Electronics and solid state power circuits have greatly facilitated the application of DC power distribution.
## Signal Transmission

### Subsea to Beach

<table>
<thead>
<tr>
<th>Within the layering of the matrix, we have these basic equations.</th>
</tr>
</thead>
</table>

Communications on Power is limited

Separate Power and Comms can achieve greater distances

Fibre optics gives
- enormous bandwidth
- increased range
- immunity to electrical interference

Satellite can throw off the tether

---

Signal Transmission is one of the most arcane areas of umbilical and control systems.

The range achievable with signals multiplexed onto the power line is limited, and the number of wells that can be interfaced to such a system is also limited. (This type of system has the benefit of minimising the number of copper cables needed in the umbilical).

Splitting signals and power onto two separate cables can achieve greater distances, as crosstalk (noise) getting onto the signal lines is substantially reduced. The limits of this technology have never been fully realised in practice. Consider the increase in bandwidth that has been achieved in recent years by modems for connecting to the internet. Similar increases in bandwidth and distance are possible for subsea electrical signal transmission, but this technology will probably never be further developed due to advances in other areas.

Fibre optics gives a quantum leap in bandwidth, greatly increased range, and immunity to electrical interference. Fibre optics are revolutionising the face of subsea umbilical systems.

A “game-changer” is satellite communications, which enables the subsea system to finally throw off its tether to the beach.
This information from the telecoms company Alcatel illustrates the stepouts that are possible with existing technology.

All the systems shown above are unrepeatered, that is, there is no subsea electronic amplification. Some of these schemes use optical pumping (Raman amplification) to regenerate signals.

In addition to the extreme distances, note the bandwidths. These are far in excess of what is necessary for subsea control, and can easily cope with any foreseeable demand. (Famous last words, think how long your first computer lasted).
### Low Earth Orbit (LEO) Satellite Link

- Constellations of low altitude satellites
- Globalstar, Iridium and Orbcomm
- Antennae do not require pointing
- Low power equipment
- Low cost equipment
- Messaging services

This technology is truly a game-changer. Forget everything you know about existing satellite systems using geosynchronous satellites at an altitude of 35,800 km: this is different.

The Iridium satellite network comprises 66 satellites in 6 different polar orbits at an altitude of only 780 km, with each orbit of the Earth taking 100 minutes. Each satellite has a link with four others, two of which are in the same orbit and two of which are in adjacent orbits.

At any one time, there will be a minimum of two satellites in contact with a control buoy, at any point on the globe. The system works by handing on the call to other satellites as the satellite with the initial contact moves out of sight of the buoy.

This technology permits the development of small, low power control buoys located anywhere in the world, controlled from any location.

With an unsteered antenna the size of a large coffee cup, installation is straightforward even for unstable wave-riding buoys. The requirement for tethers to stabilise the buoy, as used on East Spar, is eliminated.

Communications between the offshore buoy and the onshore control room can be achieved on a dial-up basis, or via the data/text messaging services that satellite vendors are now making available.

Backup and redundancy is provided by duplicating the inexpensive equipment and by allowing for a second satellite network, e.g. Globalstar as a backup to Iridium.
This image shows Iridium telephony traffic for the month of November 2003.
This proves that low earth orbit satellite coverage is truly global.
From the arcane, we move to the archaic. Surely there’s something fundamentally wrong with trying to force hydraulic fluid through a tube in order to open a valve at the far end!

Nevertheless, this technology is still useable and I will demonstrate that it has legs which can carry it into the ultra-long stepouts that are currently being considered.

The key to using hydraulic systems at long stepouts is to provide hydraulic accumulation subsea to make a ready store of energy available to open tree and manifold valves.

Savings can be effected by using single pressure systems rather than having separate lines for Low Pressure hydraulics and High Pressure hydraulics. This can be implemented by having all the valves operate from the same pressure, by using dome-charged SCSSSVs, or by generating a higher pressure subsea with a pressure intensifier.

Another option would be the all-electric wells that vendors are currently developing.
This slide illustrates charging a 250km umbilical up to working pressure. The field has three manifolds and a collection of subsea accumulators. After starting to charge up the umbilical, the pumps run continuously for one hour. The pressure at the end of the umbilical rises steadily, reaching 180 bar after 90 minutes. At this point, the accumulators are sufficiently charged to commence valve operations.
This simulation (by Svein Lileland of FMC Kongsberg Subsea AS) shows the effect of opening up a 12-well development at a long stepout.

As each of the 12 wells is opened, the supply pressure available subsea starts to fall.

The first four wells can be opened up in just over an hour, but after that, the trees are opened more slowly.

Opening up all 12 wells takes 10 hours, and then the pressure (which builds up between each tree operation) can recover fully.
Pressure intensifiers can reduce the number of hydraulic lines needed in an umbilical. ABB Seatec have used these devices successfully on a number of subsea developments.
We've considered some of the technological drivers, and we will be considering the economic drivers in a little while.

But there is another driver – the environment, and the various pressure groups that exert influence in this area.

Offshore fields may be developed as all-subsea facilities for environmental reasons. At least one field, close to shore, went subsea so that the view to sea was not spoilt by an offshore platform in an area of outstanding natural beauty.

Pipelines and umbilical systems can be installed by Horizontal Directional Drilling in areas such as that shown above, to avoid any visual impact on the surroundings.

There is another problem hidden in this scene which can affect short umbilical systems – the cliffs!
Short umbilicals may be implemented with thermoplastic hose, and hydraulic analysis of such systems requires detailed and accurate information about the volumetric expansion with pressure of the hoses, as shown above.
The hose information is used for analysis of the hydraulic systems. The analysis shown above is for the closing of a valve on a subsea tree.

The pressure starts dropping immediately, but it takes 8 minutes before the pressure has fallen sufficiently (to 25 bar) for the valve to start to close, and a total of 12 minutes for the valve to fully close. This occurs when the pressure on the line has dropped to 14 bar.

The difficulty that may be encountered in subsea to beach scenarios is that the onshore plant and the Hydraulic Power Unit may be well above sea level. Suppose the plant was set well back from the cliffs at the beach crossing, at an elevation above sea level of 120 metres. When the umbilical is vented to close a subsea valve, the pressure in the line does not fall to zero, it only falls to 12 bar due to the hydrostatic head of 120 metres of control fluid. In effect, the pressure curve shown above is displaced upwards by 12 bar, and it could take in excess of 20 minutes to close the valve, if indeed it closed at all.

The solution is to ensure that the Xmas Tree vendor is aware of the intended use, so the valve actuators can be suitably designed for this service.

But enough of short umbilicals. Let's focus on the configuration of the Snøhvit Field in Norway, with a design offset of 220km.
**Snøhvit - Control System Features**

**Water Depth**: 350 metres max  
**Design Life**: 30 Years  
**Design Offset**: 220km

- 3kV 3-Phase Power Distribution to the CDU (Central Distribution Unit), then single phase 600V distribution from the CDU to the Manifolds, with Line Insulation Monitors in each line
- Fibre Optic Communications to the CDUs with High Speed Power Line Signalling to the Manifolds.
- Fully redundant Electrical and Optical Distribution.
- Dual redundant 345 bar Low Pressure hydraulic distribution system with High Pressure Intensifiers in each SCM.
- Back-up Power Line Signalling from shore to the CDU in event of total optical system failure.
- Back-up Intervention Control System to be installed on a vessel of convenience, in the event of umbilical failure.

In essence, the Electrical Power Unit (which is normally situated in the onshore control room) has been located subsea in the CDU. Equipment such as the subsea modems, electrical power converters, and the Line Insulation Monitors have been marinised and put in the field.
Fibre-optics is used for supplying signals to the field, where an optics to electrics conversion module is used to reconstitute the electrical signal.

This can be distributed to the equipment in the vicinity using conventional well-proven electrical means (Signal on Power).

Distribution of fibre-optic from CDU1 to each of the drill centres or individual trees is not a preferred option, as it would require multiple fibre-optic connectors, each introducing further attenuation.

The distribution method is evident from the cross-section of the main umbilical and the infield umbilicals, shown below.

However, the future expansion of the Askeladd field over another 34km is achieved by an additional fibre-optic link from CDU1.
To validate the use of fibre optic distribution in the Snøhvit field, a test was carried out by ABB Seatec using 200 km of fibre optic cable, as shown below.

I must admit that the sight of a 200 km comms link on a benchtop just blows me away. Awesome!
Despite the various levels of backup built into the umbilical system, there is still a danger of total umbilical failure.

To mitigate against this situation, the Snøhvit project has a complete backup control system (BUICS – Backup Intervention Control Systems) which can be loaded onto a vessel of opportunity, sailed to the field, and plugged into the Central Distribution Unit using an ROV. This completely bypasses the main umbilical, and allows the field to be up and running again in a couple of days, while the failure in the main umbilical is rectified.

This state-of-the-art backup system reminds me of my first job in the oil industry, with ABB Seatec in 1991. I was given the task of developing the electrical equipment for an Intervention Control System for the Conoco Lyell Southern Manifold in the North Sea. In the event of a failure in the umbilical, the ICS was to be loaded onto a vessel of opportunity and . . .

Perhaps you get the picture. The old ideas keep coming round. Incidentally, my boss from that first job in the industry is present in the audience this evening. Phil Jordan, all the way from Nailsea, near Bristol in the UK.

Thanks for the opportunity, Phil, and thanks for putting up with all the dumb questions, like “So what is a moonpool, then?” He has the patience of a saint.
A problem for umbilicals in Australian waters is shipping them from the manufacturing plants. Short umbilical lengths can be transported and installed using reels, but longer lengths need midline joints or the use of carousels. Both options are unattractive. Underwater joints cause delays in the installation, for making up the joints and for testing. They are also a point of weakness, where failure may occur during operation. Carousel vessels are used in the North Sea and in the Gulf of Mexico for long stepouts, but mobilising them to this region incurs a significant cost penalty.

Equipment which works satisfactorily in the North Sea may experience premature failure in Australian waters. The warmer conditions can adversely affect umbilical systems.
The last driver for the use of Subsea to Beach umbilicals is the cost of ownership. The cost of plain vanilla umbilicals increases with stepout, but the cost increase is not linear with distance. As stepout increases, the size of electrical and hydraulic cores increases too, so the cost increases exponentially.

At some point, the umbilical no longer fits on a reel, and a carousel vessel has to be mobilised, introducing a step change in the cost of the umbilical system.

Could a simplified umbilical be used, without redundancy? Perhaps the hydraulics could be implemented by strapping coiled tubing to the main pipeline. (Remember that backup and bypass systems are well-proven and can be quickly mobilised). This could give a lower cost for the umbilical system.

An alternative to umbilicals is providing all the necessary services with a control buoy moored over the field. Indicative costs are shown for an East Spar type of buoy.

With communications provided by UHF radio, the cost starts increasing at a certain stepout because of the telecoms mast on which the onshore antenna is mounted. Advantage should be taken of any high point in the vicinity of the onshore facilities.

Using satellite communications (LEO satellites), the cost of communication is independent of stepout distance. Nevertheless, the life-cycle costs increases with stepout due to the maintenance and servicing costs, and the need to transfer men and equipment to the buoy over increasing distances.

Beyond a certain distance, boat transfers are no longer viable, and helicopters should be used. The higher line takes account of additional structure and helipad.

There is an alternative to the larger East Spar and TLP type of floating facility. Mini control buoys offer a viable and proven alternative to umbilicals for both short and long distance stepouts. They can be used for control of one or two wells, and are cheap enough to be used on a one-per-well basis for a larger field. The cost of the Petrobras 4-ALS-39 buoy was reported as only US$ 1 million.
I’m confident that the control and umbilical disciplines can provide support for subsea to beach systems of any distance, at an affordable cost.

The real difficulties lie in other areas. Turndown, rampup, liquid holdup and slugging is one particular aspect which affects the operability of these long distance subsea to beach systems.
Some people imagine that Perth, Western Australia, is a sleepy backwater. Not so, we’re on the cutting edge of new technology.

Consider the innovative East Spar buoy which was developed in this town by some of the engineers in this very meeting. So good that it was copied – there’s one just like it in South Africa!

Consider the boldness and vision of BHPBP in even thinking that the Scarborough field could be developed at such a distance offshore.

Golly, I’m excited! So what does the future hold in store?

Radio communication over long distance may make a come-back through the use of autonomous high altitude balloons, floating in the jet streams and flying back to their base when their helium runs out.

And high temperature superconductors are being developed, which may make it easier to get electrical power out to the field. But let’s not think small. Superconductors could bring to reality the Gas to Power concept, where gas is burnt offshore to generate electrical power for transfer through electrical cables to the beach. The economics are not quite right yet, with conventional cables, but superconductors may mean the end of submarine pipelines as we know them.

I’m delighted to work at INTEC Engineering where my colleagues and I get the opportunity to work on some of the longest, deepest and most challenging subsea systems.

Presentation to the Society for Underwater Technology
13 April 2005
Subsea to Beach Umbilicals - Past, Present and Future

Kevin Mullen